THE SECRET IS IN THE SLUDGE

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ABSTRACT

This paper shows how to improve anaerobic digester start-up performance through use of purpose designed biological commissioning procedures. Key data and features for the presented examples are discussed.

(i) Using directed sludge adaptation at pilot plant scale the sustainable loading rate for anaerobic digestion of fat, oil and grease (FOG) was increased from 0.7 kg FOG/$m^3_{digester}$/day (standard co-digestion conditions) to up to 2.1 kg FOG/$m^3_{digester}$/day (6.5 kg COD/m^3/day) when FOG was the sole carbon and energy source.

(ii) Through seed sludge selection using sediment from a wastewater treatment pond receiving boiling hot sugar cane molasses distillery waste (90 -100 ^oC, pH 4 – 4.5) CPG designed a digester start-up program to achieve full thermophilic treatment at 55-65 ^oC within 10 days. This design (10,000 m^3 digester) replaced a 40,000 m^3 mesophilic system reducing the system footprint and construction costs.

(iii) CPG was engaged by the Christchurch City Waste Water Treatment Plant (CWTP) in 2010 to commission their two new thermophilic sludge digesters (temperature of 55-60 ^oC) using digested mesophilic sludge as start material. An active, stable thermophilic sludge culture (7000 m^3) was produced on full scale within 40 days. The sludge digestion (16 days HRT) with the thermophilic sludge culture achieved improved biogas yield, biosolids stabilisation and VS destruction efficiency while mixed liquor VFA levels remained below 1000 ppm.

KEYWORDS

Anaerobic digestion, biotechnology, wastewater, thermophilic

1 INTRODUCTION

CPG has designed and commissioned a significant number of large anaerobic digestion facilities in New Zealand, Australia, South America and South East Asia. These have typically a digester working volume between 10,000 m^3 and 100,000 m^3 and are operated at mesophilic (30-40 ^oC) and/or thermophilic (55-65 ^oC) temperatures. The biogas is mainly used for power production (typically 1-10 MW_{el}), for production of factory process heat and/or is flared for generation of additional carbon credits.

Typical applications for the CPG digester technology would be waste water treatment in primary processing industries (meat processing plants, starch processing plants, palm oil mills), manure treatment in large feedlots (beef, dairy, pigs), dairy farm effluent treatment and biosolids digestion in municipal wastewater treatment plants

During the course of many projects it became clear that procurement, transport and addition of the anaerobic seed sludge for biological commissioning during start-up can become a significant cost and a rate limiting factor for the project completion - mainly due to the seed sludge amount dictated by the large size and working volume of the digesters.

Purpose designed cost effective procedures for procurement of large amounts of adapted seed sludge at low cost and adaptation of locally available anaerobic sludge materials (manure, surplus sludge from other digester, wastewater treatment lagoon sediment) are thus very important elements in the project cycle for the implementation of anaerobic digestion facilities.

This paper give 3 examples of purpose designed digester seed sludge adaptation procedures for the start-up of anaerobic digesters in different industries. Contrary to common practice in digester start-up (gradually adapt seed sludge over time to the conditions in the digester process) the designed procedures take advantage of the properties, physiological characteristics and requirements of the key anaerobic microorganisms to shorten the start-up time. This allows to shorten the project completion time. Results from laboratory scale, pilot plant scale and full scale applications are shown.

2 ADAPTATION TO FAT, OIL AND GREASE (FOG) DIGESTION

2.1 OVERVIEW

Fat, oil and grease (FOG) contributes to volatile solids in waste materials from food processing industries and can comprise up to 65% (w/w) of meat industry wastes. Economic recovery of FOG (lipids) is often impractical because of their association with tissue, soil or fecal matter. Wastes with high lipid contents are typically recalcitrant to biological waste treatment because of lipids propensity to form floating aggregates. The low surface area to volume ratios of these aggregates slows their degradation by microorganisms. Especially grease trap waste, flotation foams from dissolved air treatment systems in dairy and meat processing plants, palm oil mill effluent and meat byproducts fall into this category.

The anaerobic degradation of FOG is achieved by the concerted action of hydrolytic fermentative, syntrophic acetogenic (SAB) and methanogenic bacteria. Lipids are hydrolysed to glycerol and long chain fatty acids (LCFA) by microbial exolipases (Broughton et al, 1998, Jarvis and Thiele., 1997; Jarvis et al., 1998a). Glycerol from fat hydrolysis is fermented to a variety of volatile fatty acids (VFA,) alcohols and formic acid (Jarvis et al, 1998b). The SAB degrade LCFA and some VFA to acetate and hydrogen (Broughton et al.,1998) and require methanogenic bacteria to remove inhibitory levels of acetate, formate and hydrogen (Thiele and Zeikus, 1988). High LCFA contents in the mixed liquor can destabilise anaerobic digesters due to inhibition of SAB and methanogenic bacteria (Broughton et al, 1998).

To minimize the inhibition by the LCFA formation during the anaerobic digestion of FOG, CPG has therefore designed and commissioned a number of anaerobic co-digestion facilities for waste materials with high contents of FOG. In these facilities (Figure 1), the waste materials (dairy industry floatation foams, meat industry floatation foams) are blended with other low fat content co-substrates such as animal manure, paunch contents or municipal primary sludge in order to reduce the fat concentration. Typical co-digestion organic loading rates with FOG are 0.5-0.7 kg FOG/$m^3_{digester}$/day and FOG digestion contributes to up to about 50 % of the daily biogas production in a co-digestion facility.

Co-digestion requires the transport of the FOG containing industrial waste material(s) to the location of the co-digestion facility if the digester is not located on the factory premises (Figure 1B). This creates added costs and logistic constraints to transport FOG waste to co-digestion facilities.

Here we show the pilot scale test results (10 L digester) of a sludge adaptation procedure that allows the anaerobic digestion of sheep tallow (100 % FOG) in a continuously operated digester at mesophilic temperatures without addition of co-substrates. This development thus removes the dependency of FOG digestion on the availability of suitable co-substrates.

2.2 METHODS

Analytical methods and tallow preparation for the tests were as described elsewhere (Broughton et al., 1998). The test digester was a 10 liter CSTR digester maintained at 35 +/- 2 ^{o}C.

The digester seed sludge source was from a meat processing plant digester as described elsewhere (Broughton et al., 1998).

2.3 RESULTS AND DISCUSSION

The results of the designed sludge adaptation for effective mesophilic digestion of waste with 100 % FOG content in the dry matter are shown in Figure 2. Initially the stored digester sludge was re-activated with the addition of glucose until a stable methane production of 0.8 m^3 methane (STP)/$m^3_{digest6er}$/day was reached (around day 15-20). From day 20 onwards the glucose addition was stopped and a tallow emulsion was daily added as sole carbon and energy source at the daily dose indicated in Figure 2 (from a concentrated stock solution; Broughton et al, 1998) The daily tallow dosing rate was initially kept within the proven range for operating full scale co-digestion systems (0.7 – 0.9 kg FOG/$m^3_{digester}$/day; see Figure 1). The methane production rate of the test digester at this dosing rate was as expected between 0.9 – 1.0 m^3 methane (STP)/$m^3_{digester}$/day.

From day 28 – 36 the average daily tallow dose was increased to 1.45 kg FOG/$m^3_{digester}$/day. The daily methane productivity of 2.0 - 2.2 m^3 methane (STP)/$m^3_{digester}$/day responded immediately to the increased tallow dose and the methane recovery indicated quantitative conversion of the added tallow COD to methane. The pH in the digester mixed liquor remained stable under these conditions.

From day 36 – 41 the daily tallow dose was increased to about 2.1 kg FOG/$m^3_{digester}$/day. At this point, the digester sludge started to show metabolic stress and reached the limit of FOG digestion to methane (Figure 2) . This was indicated by a disproportional increase in the methane productivity and accumulation of intermediates such as volatile fatty acids (acetic acid, data not shown).

In order to test the resilience of the "stressed" anaerobic sludge to FOG overdosing under these conditions, a one-off tallow dose of 4.8 kg FOG/$m^3_{digester}$/day (Figure 2, day 43) was applied. The methane production dropped temporarily from approximately 2.2 m^3 methane (STP)/$m^3_{digester}$/day to 0.4 m^3 methane (STP)/$m^3_{digester}$/day. But the methane production rate of the adapted culture recovered remarkably fast within 2 days to 1.2 – 1.5 m^3 methane (STP)/$m^3_{digester}$/day when the tallow addition was resumed at a rate of 1.1 – 1.2 FOG/$m^3_{digester}$/day. The same tallow digestion and methane production dynamics were observed when another tallow shock load challenge of the adapted digester culture was tested between days 80 - 85 (Figure 2).

The feeding of the adapted culture with tallow as sole source of carbon and energy was continued for a total of 140 days without any signs of culture degeneration or washout from the continuously operated laboratory scale digester system (data not shown).

2.4 CONCLUSION

The presented data have shown that the fundamental biochemical dynamics of the anaerobic digestion of tallow to biogas demonstrated previously in batch digesters (Broughton et al, 1998) can also be applied to continuously operated mesophilic digesters. Repeated dosing of the adapted digester culture with tallow at a rate that was non inhibitory to SAB and methanogenic bacteria produced increased methane productivity from FOG digestion . These rates were 200-300 % increased when compared to methane production rates that are typically observed in co-digestion systems. We conclude that the unique microbial detoxification reactions for highly inhibitory unsaturated long chain fatty acids (oleic acid) discovered previously (Broughton et al., 1998) prevail also in continuous culture when FOG is added to anaerobic digester sludge at high rates. The sludge adaptation tests have further shown that the addition of low fat content co-substrates is not essential for the conversion of high fat content waste materials to methane and CO_2 (biogas).

This new result demonstrating the technical potential of the designed sludge adaptation procedure to the continuous anaerobic digestion of FOG as sole carbon and energy source opens thus the opportunity for installation of dedicated high rate digester systems for waste with very high FOG contents when commissioned with appropriately adapted anaerobic seed sludge. These dedicated digesters can be installed on factory sites or municipal wastewater treatment plants providing additional boiler fuel/genset fuel without the need to import additional co-substrates for the FOG digestion.

3 STARTING THERMOPHILIC TREATMENT WITH POND SLUDGE

3.1 OVERVIEW

The wastewater from sugar cane molasses based distilleries is notoriously difficult to treat (Wilkie et al., 2000; Satyawali Y and M Balakrishnan, 2008). It has a high COD content (70,000 - 200,000 mg COD/litre), a low pH (pH 4 - 4.5), a high salt content (5-12 g potassium/litre) and high sulphate levels (4-10 g SO_4/litre). About 40-50 % of the wastewater COD is refractory under anaerobic conditions. Aerobic treatment is virtually impossible due to the high COD content and high aeration costs. In addition, the wastewater leaves the distillery typically at 70^o-90^o C. Traditional low rate anaerobic open pond treatment systems for molasses distillery wastewater are space consuming (4 ha for 3 million litre alcohol/annum), produce significant odour emissions (H_2S, volatiles), methane emissions (biogas) and leave incompletely treated wastewater.

Improved **C**overed **I**n **G**round **A**naerobic **R**eactor treatment systems (CPG design; Figure 3, CIGAR™) are available that reduce the comparable footprint (1 ha for distillery with 3 million litre alcohol/annum) and provide significant benefits through substantial biogas and odour capture and greenhouse gas emission reductions. However, they have a significant footprint and require an initial wastewater cooling pond or cooling tower prior to the CIGAR™ which results in significant biogas losses and emissions of odour, methane and volatiles prior to anaerobic treatment.

Recently we have presented a novel thermophilic/mesophilic hybrid anaerobic digester system (Thiele, 2011) for direct treatment of boiling hot, fresh sugar cane molasses distillery waste (90 ^oC, pH 4-5). In the novel hybrid system, a tank based initial cooling tower/mixing stage is operated as thermophilic flocculent sludge **U**pflow **A**naerobic **S**ludge **B**lanket (UASB) digester (50 - 65^{o}C operating temperature, neutral pH) seeded with anaerobic sediment from existing distillery treatment ponds. Thermophilic UASB effluent is polished in a subsequent sub-thermophilic (45 ^{o}C) covered lagoon (CIGAR™) stage. Settled anaerobic digester sludge and effluent from the sub-thermophilic stage are returned into the thermophilic stage for pH adjustment. This flocculent sludge UASB system is very robust as it does not require granular sludge formation for operation (Thiele, 2011). We report here the results from the start-up of the flocculent sludge based thermophilic UASB pilot plant with anaerobic sediment from pre-existing distillery ponds in a sugar cane molasses distillery in The Philippines. A performance comparison to mesophilic treatment systems for the same type of wastewater is also shown.

3.2 METHODS

Analytical methods and tests were conducted as described elsewhere (Thiele, 2011). The test digester was a UASB pilot scale digester maintained at 53 +/- 3 ^{o}C (Thiele, 2011).

The thermophilic UASB digester seed sludge source for the full scale UASB digester was obtained from a molasses distillery effluent treatment lagoon adjacent to the installation (Thiele, 2011).

3.3 RESULTS AND DISCUSSION

Thermophilic digester systems (55 - 65 ^{0}C) are typically superior to mesophilic digester systems (30-40 ^{o}C) because all metabolic processes operate at a 2-3 times faster rate. This means that smaller digester tanks achieve treatment of the same wastewater flow when compared to a mesophilic process.

The selection of the right source of suitable digester seed sludge is the key to a successful biological commissioning after the digester facility construction is completed. Recently we demonstrated that thermophilic anaerobic seed sludge adapted to the waste can be readily obtained from existing molasses distillery effluent treatment ponds that are operated at ambient temperature (Thiele, 2011). The resident methanogenic consortia in the effluent treatment pond sediment (in situ temperature: 30-45^o C) incubated under defined laboratory conditions showed 3-fold improved methane production rates when incubated above 50^o C versus below 45^o C

(Thiele, 2011). Thus mesophilic bacteria that were active below 45 °C and thermophilic bacteria active above 50 °C co-existed in significant numbers in the pond sediment. This was an important finding because the efficient start-up of full scale thermophilic digester processes hinges critically on the availability of large amounts of suitable, adapted, active anaerobic bacteria that can operate at temperatures of 50-65 °C.

Figure 4 gives a typical flocculent UASB digester start-up time profile with the pond sediment at 35-40 °C (day 0 – 30). A permanent temperature shift from 40 °C to at 53 +/- 3 °C in the pilot plant digester on day 30 was completed within 48 hours (day 30-32) and produced daily biogas production (from day 32 onwards) that was comparable to the production at 40 °C (prior to day 30, Figure 4). The start-up operation summary results shown demonstrate that the distillery waste treatment pond sludge was well pre-acclimatised to mesophilic and thermophilic conditions. Very high specific loading rates of the anaerobic pond sludge in the UASB reactor of up to 0.6 kg $COD.kg_{VSS}^{-1}.day^{-1}$ were sustained under thermophilic conditions in the UASB reactor (Figure 4).

A full scale version of this thermophilic flocculent UASB hybrid technology was installed in 2008/09 at a molasses distillery in The Philippines and started with pond sediment. Table 1 compares the initial performance of the thermophilic hybrid system with the previously installed mesophilic CIGAR™ based digester system for the same type of wastewater in Thailand (see Figure 3 for photo). The thermophilic system offers a smaller footprint, a smaller digester size and a higher organic loading rate when compared to the mesophilic system. However, the hydraulic residence time in the mesophilic system (57 days) is significantly longer than in the thermophilic hybrid system (18.5 days). This resulted in a higher methane yield in a mesophilic CIGAR™ compared to a thermophilic UASB system (Table 1).

3.4 CONCLUSION

In conclusion, the data show that wastewater treatment pond sediment from highly loaded treatment lagoons in sugar cane molasses distilleries can be used as seed sludge for thermophilic and for mesophilic anaerobic digesters.

The data suggest that thermophilic digesters might also be easily started up with pond sediment in other industries where hot process wastewater enters a pond without prior cooling such as in pulp & paper processing factories, biofuel production plants and palm oil mills.

4 THERMOPHILIC DIGESTION OF MUNICIPAL BIOSOLIDS

4.1 OVERVIEW

The Christchurch City Waste Water Treatment Plant (CWTP) was upgraded in 2010 from four mesophilic digesters (4 x 4,500 m^3, D1 – D4) to a **T**emperature **P**hased **A**naerobic **D**igester (TPAD) system consisting of two new thermophilic digesters (7,000 m^3 each, D5, D6) followed by the existing four mesophilic sludge digester D1 – D4. A conventional start-up of the thermophilic digesters with thermophilic seed sludge would have required the procurement of approx. 1,400 m^3 adapted thermophilic seed sludge which was impractical because no other thermophilic digester plants exist in the Canterbury region.

CPG was therefore contracted for the biological commissioning of digesters D5 and D6 using mesophilic anaerobic sludge from digesters D1-D4 as seed sludge for the thermophilic digesters.

The start-up of thermophilic digesters with mesophilic digesters sludge as seed sludge is a well proven procedure. In short, mesophilic anaerobic digester sludge is known to always contain a small and complete complement of thermophilic anaerobic bacteria as a background population. These thermophilic bacterial populations have the capacity for effective anaerobic digestion of municipal biosolids at 55-65 °C.

Rapid heating of the mesophilic sludge from 35 °C to temperatures above 50 °C will kill the mesophilic bacteria and provide suitable conditions for the thermophilic background population to multiply and grow their population using organics released from dead mesophilic bacteria and residual biosolids materials. However, when this standard thermophilic digester start-up procedure was tested at CWTP laboratories it was found that a significant risk existed for excessive foam formation and digester inhibition by high levels of VFA (up to 8,000 - 10,000 ppm total VFA in the liquor) during the thermophilic digester start-up with the locally available mesophilic digested sewage sludge.

4.2 METHODS

CPG designed a specific thermophilic digester start-up procedure for the thermophilic digester D5 and D6 that included the following additional precautionary measures in the temperature transition to prevent excessive foaming and VFA accumulation:

(A) Digesters 5&6 were initially operated with mesophilic sludge and CWTP raw sludge biosolids at 35-37 ^{o}C until a stable mesophilic sludge digester system was established in the two new digesters D5 & D6.

(B) Once stable mesophilic digestion was proven, the feeding of the digester transitioning to thermophilic conditions was reduced until the daily biogas production was at less than 25 % of the normal mesophilic daily biogas production in the digester. This starvation took about 10 days. The purpose of step (B) was to exhaust most digestible materials and shrink the size and biomass of the resident mesophilic bacteria to reduce the foaming risk during the subsequent temperature increase step.

(C) To prepare the mesophilic sludge for the thermal lysis step, the temperature in the “starving” digester was gradually increased to 42 ^{o}C and held at that temperature without any feeding until biogas production had further decreased. At this point the digester mixing with biogas was stopped and mixing was entirely by hydraulic mixing.

(D) The mixed liquor level in the digester tank was then lowered by about 15 % to provide additional storage space in the event of excessive foam formation during the temperature transition from mesophilic to thermophilic operating conditions. The transitioning digester remained in batch mode without feeding.

(E) The operating temperature in the transitioning digester was rapidly increased from 42 ^{o}C to 55 ^{o}C at a ramp rate of about 9 ^{o}C/day using all heat available on site. This took about 35 hours to transition the digester from 42 ^{o}C to 55 ^{o}C. The transitioning digester remained in batch mode without feeding.

(F) Then biogas production, mixed liquor pH and mixed liquor volatile fatty acid levels were monitored 3 times/week while the digester was kept in batch mode until biogas production started. Feeding was resumed when considered appropriate by the CPG process advisor.

4.3 RESULTS AND DISCUSSION

The results of this start-up procedure are shown in Figure 5. During the complete course of the thermophilic start-up the mixed liquor pH in the thermophilic digester remained between pH 7.3 and 7.6 and no digester foamimg was noted. The total VFA levels remained below the maximum permitted limit of < 2,200 mg/L total VFA (Figure 5). These parameters indicated that the pre-starved mesophilic sludge did not release excessive amounts of lysis products when the temperature was rapidly increased and that the thermophilic culture was stable from the beginning.

Two small raw sludge feed pulses dosed to the digester tank at 80 hours and 200 hours of thermophilic operation resulted in the desired production of additional acetic acid that was needed to grow a strong population of new thermophilic acetate degrading methanogenic bacteria (Figure 5). A suitable level of acetic acid of 1000-1500 ppm was reached from about 300 hours after completion of the temperature transition (Figure 5). This was the most important milestone in the biological commissioning programme because acetic acid conversion to methane accounts for approximately 2/3 of the total biogas production in a thermophilic sludge digester. At the same time the production of high levels of propionic, isobutyric and butyric acid was prevented due to presence of an active population of thermophilic SAB (Figure 5). This facilitated the growth of thermophilic acetate degrading bacteria because high levels of propionate/butyrate are known to inhibit their growth.

Consistent with this microbiologically designed commissioning strategy, the thermophilic acetate removal and the hourly methane production rate started to increase at 600 hours (Figure 5). At this point gradual feeding of the thermophilic digester culture with raw sludge and digester mixing with biogas were resumed.

The design loading rate with raw sludge of 455 m^3/day at 55 ^oC was reached at around 1150 hours - about 600 hours after the first growth af thermophilic acetate degrading methanogenic cultures was observed (Figure 5).

The thermophilic start-up of the 2nd digester (D6) with mesophilic seed sludge using the same procedure produced virtually identical results (data not shonw) showing the technical robustness and resilience of the designed start-up procedure.

4.4 CONCLUSION

In conclusion, the results presented here have shown that biological commissioning risks for the start-up of thermophilic digesters can be significantly reduced if the essential physiological requirements of the key rate limiting bacterial trophic groups are taken into consideration (methanogenic bacteria and especially acetate grading thermophilic methanogens). Digester foaming and production of inhibitory levels of propionate, butyrate and isobutyrate were safely prevented by the special sludge starvation step prior to rapid temperature increase and exclusive use of hydraulic digester mixing in the critical start-up phases.

CPG's methodology described above is entirely based on the use of known principles of the anaerobic digester physiology and operation. The procedure is thus readily transferable to the start-up of other thermophilic industrial or municipal digester.

5 SUMMARY AND OVERALL CONCLUSIONS

This paper has shown that even in the presence of extreme wastewater properties of

- Very high content of FOG
- Low pH (pH 4 - 4.5)
- High wastewater temperature (90 C)
- High salt content

a number of cost effective and robust anaerobic digester process options exist than can be started up with purpose designed procedures within 10-40 days using readily available local seed sludge materials. This is a significant advancement over the current practice of start-up for anaerobic digesters.

The methodology presented combines state of the art digester process science (microbial biotechnology, chemistry; pretesting in laboratory and pilot scale) and process engineering (automation) to design digester start-up procedures that are reliable and repeatable. In the overall digester facility construction project cycle, these purpose designed digester start-up procedures allow project completion ahead of schedule and contribute thus significantly to overall digester facility delivery cost savings.

The last point is a very important aspect in digester facility projects with a high expectation of early delivery of contracted daily methane production targets.

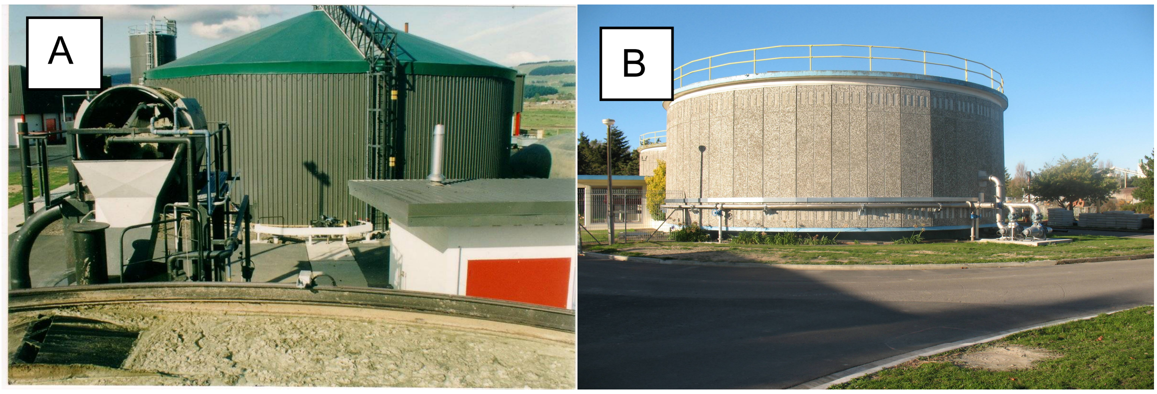

Figure 1: Examples of anaerobic Co-digestion plants in New Zealand

(A): Fortex Silverstream digester in Mosgiel, NZ (1990). This digester (background) was designed for digestion of a mixture of meat processing plant DAF flotation foams (foreground) at 35-37 °C. The methane productivity was in the range of 1.3 $V_{methane}/V_{digester}$/day and the FOG content in VS was about 25 %.

(B) Palmerston North City Council (PNCC) digester for co-digestion of dairy factory DAF float (2010). The methane productivity is in the range of 0.9 $V_{methane}/V_{digester}$/day and the FOG content in VS is about 25 %.

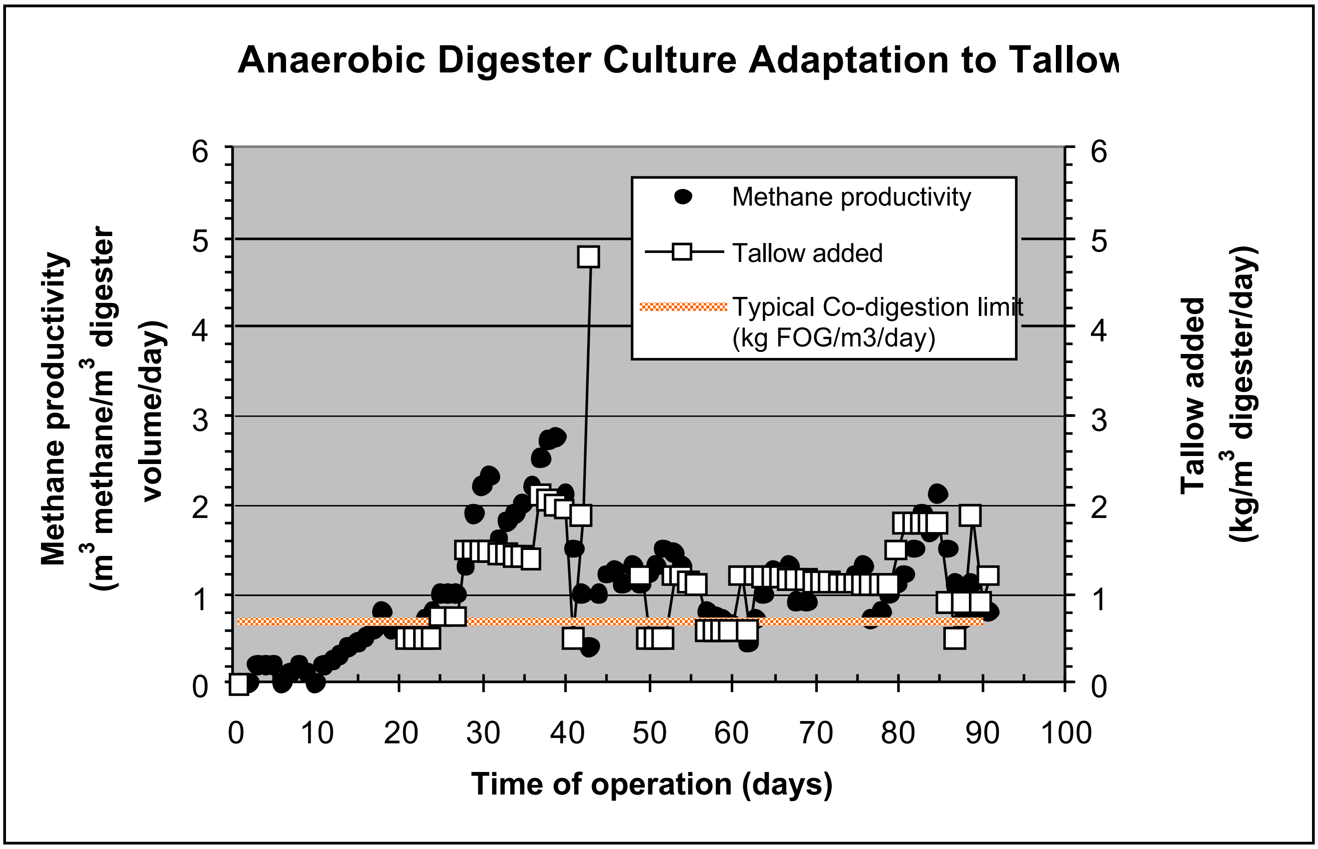

Figure 2: Example for the successful adaptation of anaerobic digester sludge to growth and methane production from FOG (tallow) as sole source of carbon and energy. Between day 1-20 the digester was fed only with carbohydrates. Between days 21 - 90 FOG (tallow) was provided as sole source of carbon ad energy. The COD recovery of the added FOG in the captured methane was >90 %.

Figure 3: *Overview of the mesophilic CIGAR™ digester system at Thai Agro Ethanol in Thailand (2005). This system treats 700 m³/day molasses distillery waste with a COD content of up to 200,000 mg COD/L.*

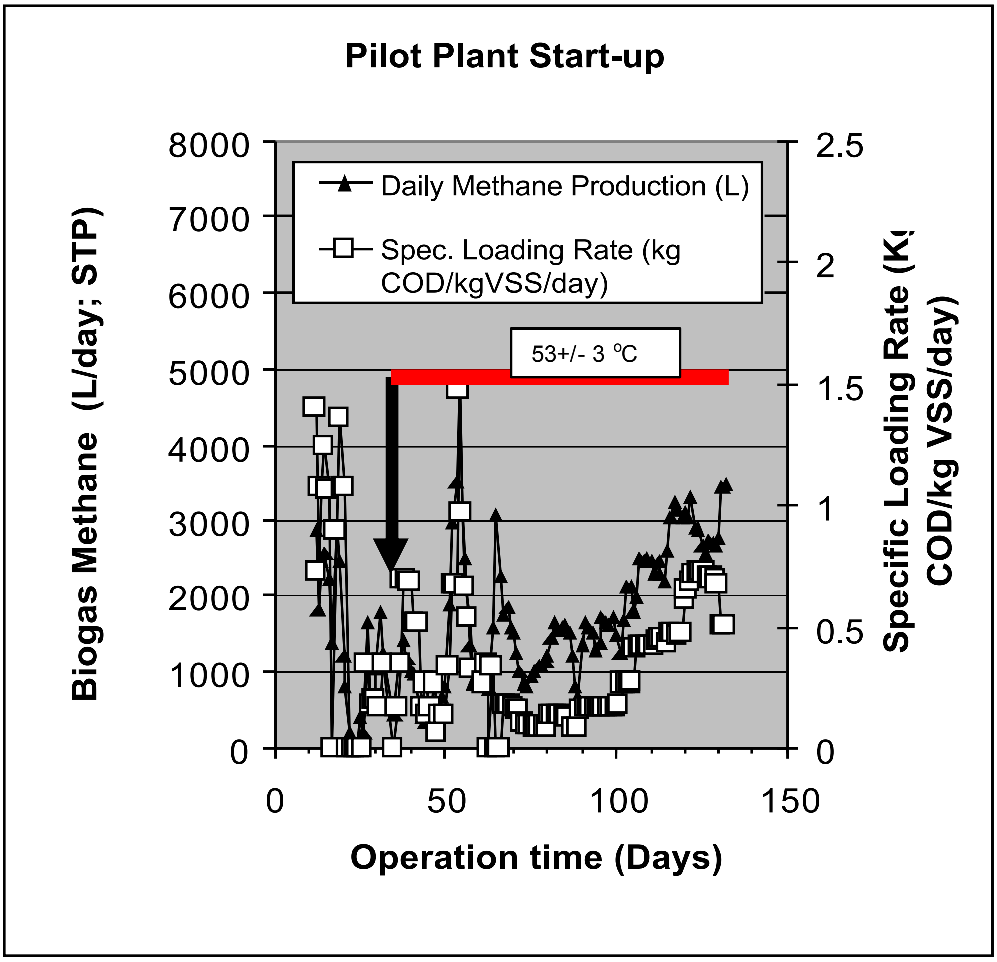

Figure 4: *Example for the successful rapid start-up of a thermophilic flocculent UASB digester with anaerobic wastewater treatment pond sediment from a sugar cane molasses distillery. Arrow: start of thermophilic operation of the UASB digester seeded with mesophilic pond sediment..*

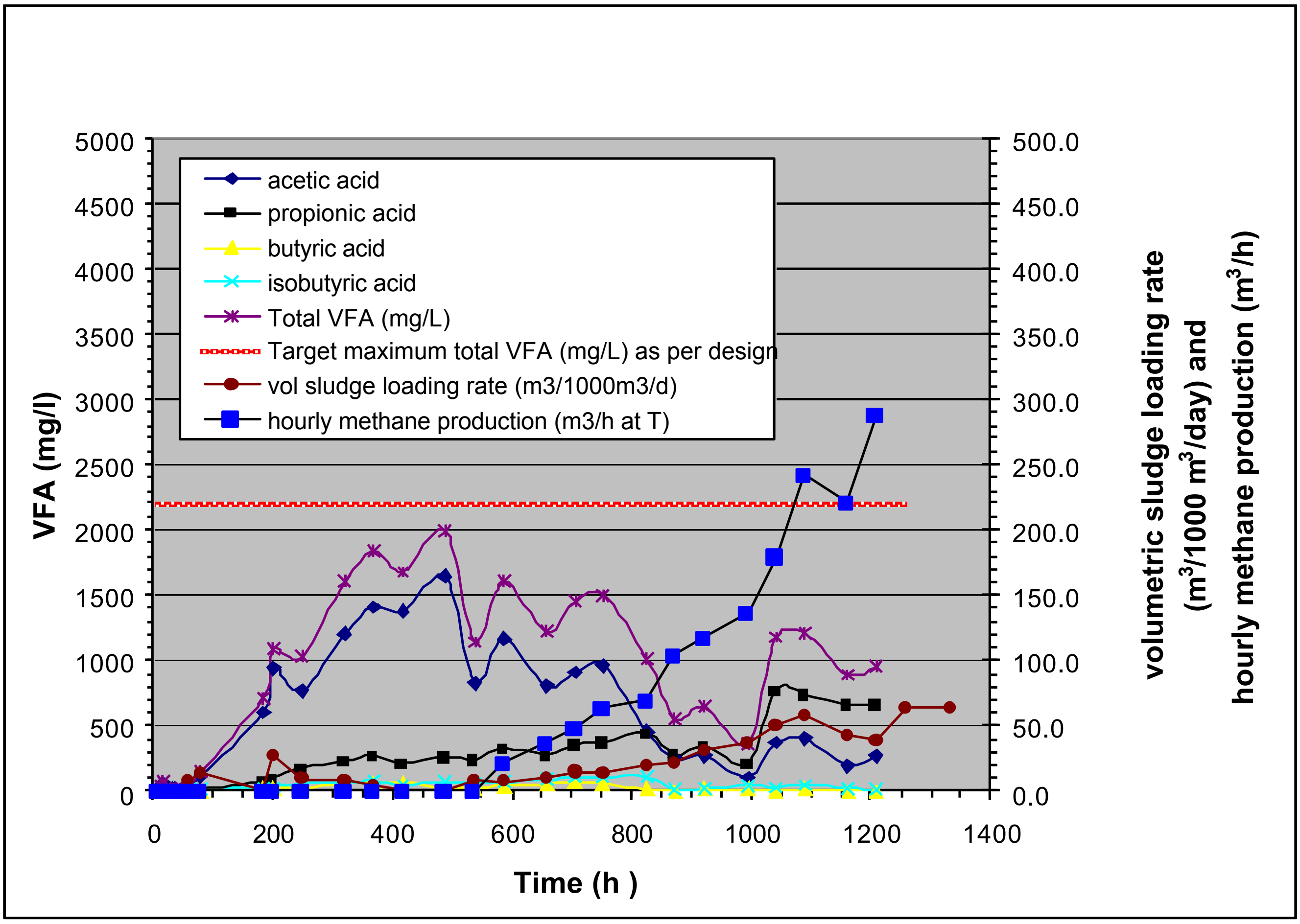

Figure 5: Christchurch Waste Water Treatment Plant (CWTP) thermophilic sludge digester D5- start-up profile with mesophilic seed sludge after heating to 55 °C. Values for total VFA and individual VFA species are for the mixed liquor composition in the digester. The digester pH remained stable at pH 7.3 - 7.6 in this period

Table 1: Comparison of a full scale mesophilic digester system and thermophilic digester system both started up with ambient temperature wastewater treatment lagoon sludge from the distillery site.

Parameter	**Units**	**Thermophilic Hybrid System ABSOLUT Distillery The Philippines (2009)**	**Mesophilic System TAE - Thai Agro Ethanol Thailand (2005)**
Wastewater Composition			
Wastewater pH		4.5 - 5	4.5 - 4.8
Wastewater temperature	^oC	90-100	80-90
COD	mg/kg	140,000	180,000
Moisture	mg/kg	880,000	850,000
Total Solids	mg/kg	120,000	150,000
Volatile solids	mg/kg	94,800	120,000
Sulphate (SO4	mg/l	3,700	8,000
Potassium	mg/kg	10,000 - 14,000	6000 - 9000
Sodium	mg/kg	340	560
Sulphur	mg/kg	1200	2700
Digester System Operation			
Digester volume	m^3	13,000	40,000
Digester Temperature	^oC	55 - 65	35 - 39
Digester pH		6.8 - 7.4	6.8 - 7.2
Digester loading rate	kg COD/m^3/day	10	3.1
Biogas methane content	% (V/V)	55-60	50-55
Operational methane yield at 700 m^3/day waste flow	(m^3 methane/ kg COD added)	0.16	0.19
System footprint	m^2	approx. 2,500	approx. 10,000

ACKNOWLEDGEMENTS

The assistance by Michael Broughton during the completion of the sludge tests for FOG degradation is gratefully acknowledged.

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