TRADE WASTE TREATMENT IN MUNICIPAL SLUDGE DIGESTERS

Jürgen H Thiele
CPG (NZ) Ltd, Dunedin, New Zealand

ABSTRACT

Natural gas costs, electricity costs and landfill gate fees in New Zealand increase continuously and affect the industrial sector and waste treatment service providers. CPG assisted therefore the Palmerston North City Council (PNCC) to upgrade its Totara Road wastewater treatment plant (WWTP) sludge digesters to 4 fold improved biogas production capacity through co-digestion of industrial trade waste together with primary sludge. The purpose was to extend the landfill life and produce additional renewable electricity via biogas use in a dedicated new genset with export of surplus power to the grid. The existing digesters were upgraded with a novel mixing system and recuperative sludge thickening without construction of new digester tanks. The digester mixing system upgrade design, construction and commissioning was completed in 2012. The digesters have now 400 % of their original design biogas production capacity (from 1,500 m^3/day to about 6000 m^3/d) with the option to produce biogas from additional industrial and trade waste such as cheese whey, grease trap waste and dairy wastewater flotation foams. The municipal digester capacity upgrade to co-digestion of selected trade waste was achievable with an attractive payback period (< 2 years).

We present the technical design rationale to upgrade municipal sludge digesters without interruption of the WWTP operation. The results from the digester operation for co-digestion of primary sludge and dairy factory DAF sludge are shown as examples. CPG estimates that co-digestion of high strength highly biodegradable trade waste and industrial and primary processing industry byproducts in municipal plants increases the national biogas production potential on WWTP's from 0.45 PJ biogas/annum to approximately 1.9 PJ biogas/annum and renders the WWTP operation energy self sufficient.

KEYWORDS

Sludge digesters, trade waste, co-digestion, biofuel, cogeneration, regional digester facility

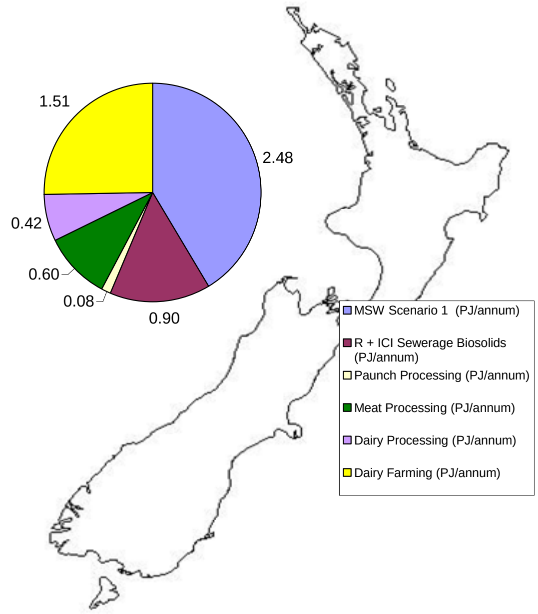
1 INTRODUCTION

The biofuel recovery through combined digestion (co-digestion) of selected trade waste materials, septage, grease trap waste, animal manures, cheese whey, industrial flotation foams, primary sludge (PS) and waste activated sludge (WAS) is a well proven and commercially beneficial method. The Danish government started a respective national initiative in 1988 (Al Seadi, 2000). This leading example has been widely followed throughout Europe and North America with combined digestion of industrial waste, manure and municipal biosolids in a large number of regional municipal, agricultural and industrial digester facilities (Al Seadi, 2000).

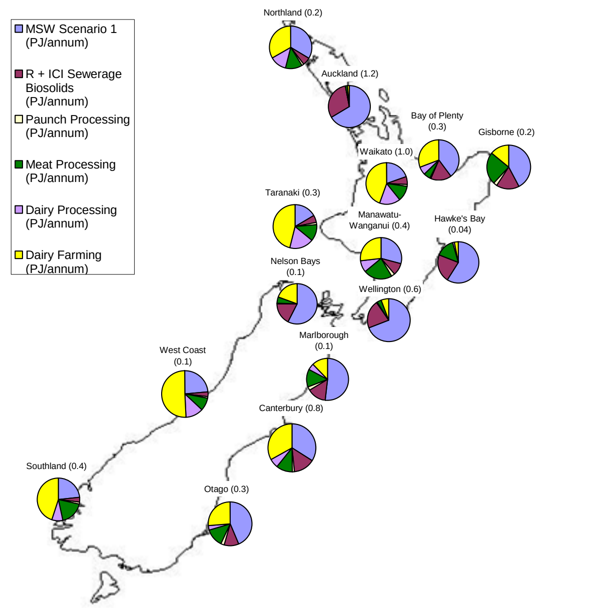
A recent detailed national survey of the NZ resource potential for biogas recovery identified a technical potential of approximately 3 PJ biogas via co-digestion of industrial and municipal waste materials (Thiele, 2007). The survey (Figure 1) concluded that the generation of electricity with re-use of generator waste heat to satisfy the digester heating requirements was a preferred biogas end use in this case. 3 PJ of biogas used for generation is equivalent to about 5-7 % of the average annual national natural gas consumption used for electricity production (Dang et al., 2007).

Figure 1: NZ National Energy Potential and resource distribution for co-digestion of various industrial, agricultural and municipal waste materials (Thiele, 2007). Values given for each sector are in PJ/annum. 1 PJ =

277.8 GWh. The base year is 2006. The energy required for digester operation is subtracted from the presented values. **R+ICI Sewerage Biosolids:** Residential plus Industrial, Commercial, Institutional wastewater biosolids; **Meat Processing:** Flotation foams from meat processing plant effluent treatment; **Dairy Processing:** Flotation foams from dairy processing plant effluent treatment.



Estimate of Nett National methane bioenergy potential from each sector (given in PJ methane biofuel/year)
Note: The processing energy requirement (heat, power) is assumed to be covered from the produced methane and is already subtracted



Regional breakdown of current Nett methane biofuel production potential from major wastes in regional areas. The process energy required for methane production (power, heat) is already subtracted.
The estimated total recoverable methane energy value for each region is given in PJ methane/yr in parenthesis
Values were calculated using MSW Scenario 1 and biosolids processing from domestic sewage + ICI sewage.

A full digester plant life cycle analysis (including environmental costs & energy usage in construction, operation and energy costs for digester sludge dewatering and transport) demonstrated an energy output /energy input in ratio in the order of 7-8 units biogas output/ 1 unit of total energy input (Thiele, 2008). However, the primary environmental benefit of co-digestion was the effective diversion of highly putrescible organic waste from landfills and land disposal with concurrent abatement of greenhouse gas emissions and options for reduction of soluble nutrient discharge (Thiele, 2008). Thus the construction of dedicated co-digestion facilities in New Zealand could be of some national relevance and highly beneficial on energetic and environmental grounds. In particular, by reducing carbon footprints in power generation and through waste stabilization, production of renewable electricity and abatement of a range of greenhouse gas emissions (methane, carbon dioxide, N_2O).

CPG New Zealand has successfully designed, constructed and commissioned a number of well mixed (10-20 $W/m^3_{digester}$ mixing energy) waste co-digestion facilities with high volatile solids (VS) loading rates (4 - 5 kg VS $m^{-3}_{digester}.day^{-1}$), high biogas productivities (2 - 3 $m^3_{biogas}.\ m^{-3}_{digester}.day^{-1}$) and short hydraulic residence times (10-15 days). These systems use improved gas recirculation mixing, mechanical mixing (EarthPower Digester Facility, Sydney) or hydraulic mixing (Chapel Street Digesters, Tauranga) and have the capability to process up to 3 times the organic load of comparable municipal sludge digesters. However, the construction of new co-digestion facilities is quite capital intensive and the economic operation new co-digestion facilities relies thus on collection of high gate fees for the waste materials (Thiele, 2000; Hearn and Thiele, 2004).

A number of municipal wastewater treatment plants in New Zealand employ anaerobic digesters with floating roofs, limited mixing, mesophilic operation temperatures (35-40^o), low organic loading rates (about 1.5 kg VS. $m^{-3}_{digester}.day^{-1}$), long hydraulic residence times (15-20 days) and low biogas productivities (about 0.7 $m^3_{biogas}.\ m^{-3}_{digester}.day^{-1}$). Therefore practical and economic ways to improve the throughput and biogas production from these sludge digesters are highly desirable, especially if acceptance of trade waste and industrial byproducts leads to the collection of additional gate fees from the digester operation. Due to lower capital costs required for an upgrade of an existing digester versus construction of a new digester plant, this approach could realize lower waste disposal fees for waste producers and thus be more cost effective and appropriate in the New Zealand context and, by diverting highly putrescible waste from landfills, extend the economic life of existing landfills. This paper presents a successful strategy, the approximate costs and the results of the realization of this plan at the Palmerston North City Council WWTP.

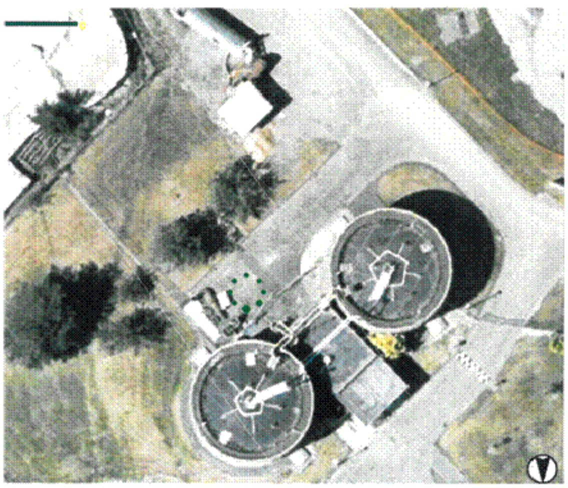
2 RESULTS AND DISCUSSION

2.1 PNCC DIGESTER PLANT UPGRADE STRATEGY

2.1.1 STATUS PRIOR TO THE UPGRADE

The Palmerston North City Council (PNCC) has completed the installation and operation of a 750 KW_{el} generator at its wastewater treatment plant (WWTP). It is planned to operate the generator on a mixture of natural gas, biogas from primary sludge and trade waste co-digestion at the WWTP and landfill gas recovered at the adjacent landfill. The PNCC WWTP operates successfully two mesophilic sludge digesters (total combined working volume, 2,700 m^3, see Figure 2 for aerial view) for primary sludge digestion.

Figure 2: PNCC sludge digesters tank 1 and tank 2– aerial view. Note the pentagonal biogas ring mains on top of both digesters with biogas feeder "spokes" leading to earlier installed ineffective Pearth lances. Bar: 13.5 meter.



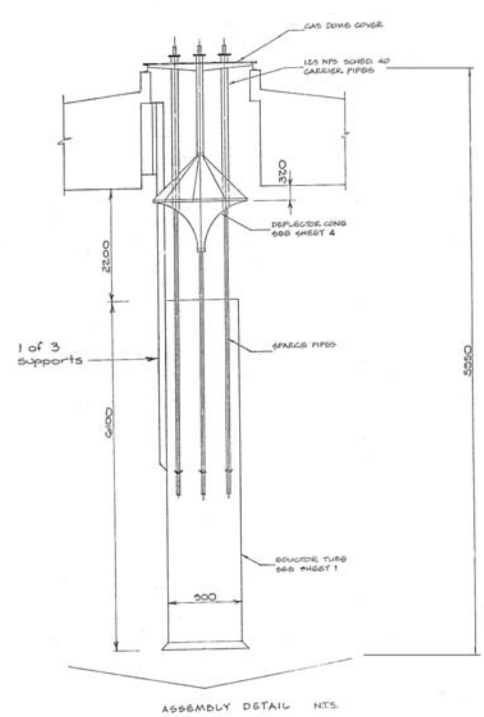
Pre-thickened primary sludge at about 4 % total solids (TS) content with about 80 % volatile solids (VS) in dry matter (TS) was digested at a nominal hydraulic residence time of 22- 28 days. The achieved volatile solids reduction of 50-55 % and the biogas yield (1.1 m^3/kg VS destroyed) were within expectation for primary sludge digestion. Volatile acid (VFA) levels are typically < 100 ppm and alkalinity in the digester mixed liquor > 1800 ppm respectively indicating a stable digester operation. However, the biogas productivity of the PNCC sludge digesters (0.6 – 0.7 m^3. $m^{-3}_{digester}$) was low with only about 1/3rd of the productivity that is regularly achieved in industrial sludge digesters. This indicated that the digesters were insufficiently mixed achieving low contact between the anaerobic sludge and fresh feedstock.

2.1.2 REVIEW OF DIGESTER MIXING LIMITATIONS PRIOR TO THE UPGRADE

In September 2008, CPG conducted a review of the current digester operations and mixing system. The digesters were individually mixed by a dual system. Firstly, the mixed liquor was re-circulated by pumping through a heat exchanger mixing the digester 24 hours per day at a nominal energy input of 3.5 W. $m^{-3}_{digester\ working\ volume}$. This system was effective but did not reach the recommended 10-20 W. $m^{-3}_{digester\ working\ volume}$ digester mixing energy input. In addition, the biogas blower for the biogas recirculation mixing operated for 8 hours/day through a central eductor tube (Figure 3) with a nominal mixing energy transmission of approximately 11 W. $m^{-3}_{digester\ working\ volume}$. Thus the dual mixing system supplied for 8 hours/day digester mixing energy within the recommended range (10-20 W. $m^{-3}_{digester\ working\ volume}$) and for 16 hours/day, below the recommended range. This irregular mixing for 16 hours/day was expected to lead to sludge settlement, limited mixing, limited sludge biomass contact and reduced heat supply to the active bacteria and therefore a reduced biogas production capacity.

A potential secondary digester mixing issue was discovered in the review. Mixing with the central eductor tube mixer with deflector cone would penetrate only a few meters from the centre leaving a large peripheral proportion of the digester working volume virtually “under mixed”.

Figure 3: Central eductor tube and deflector cone in the current digester mixing system used to mix the digester and to splash/spread mixed liquor onto top of scum layer to reduce scum formation.



PNCC commissioned therefore CPG in September 2008 to conduct a digester mixing performance test using the well proven Lithium tracer test. The results are shown in Figure 4.

The batch test with the Lithium tracer showed that about 15-20 % of the digester volume (difference between solid line and dotted line in Figure 4) were filled with settled digester sludge that was not mixed and thus resulted in reduced digester capacity and working volume.

Determination of the effective digester Hydraulic Residence Time (HRT):

The effective hydraulic residence time is defined as:

(1) $HRT_{EFFECTIVE}$ (days) = mixed digester volume (m^3) / average daily feed rate ($m^3.day^{-1}$)

The results of the effective hydraulic residence time determination are shown in Figure 5 below. The effective HRT in digester 1 without mixing system upgrade and with 8 hours/day biogas recirculation mixing was 13.2 days

Figure 4: Lithium tracer mixing test in batch operation of the PNCC digester 1.

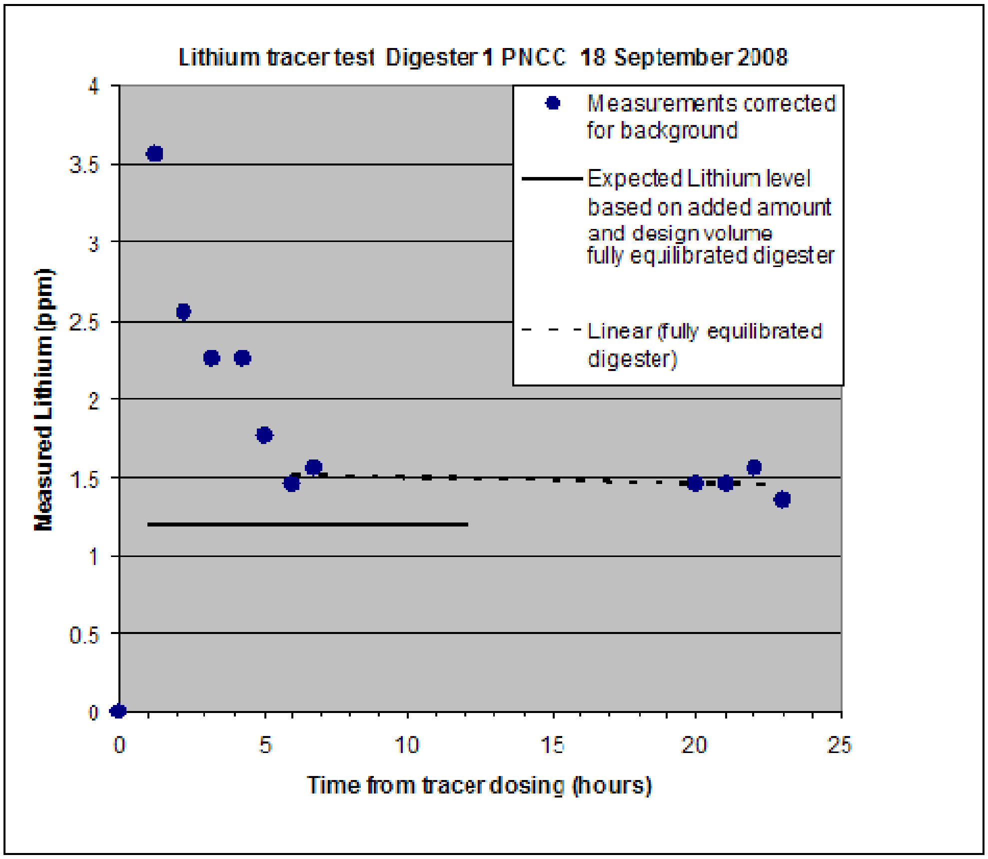
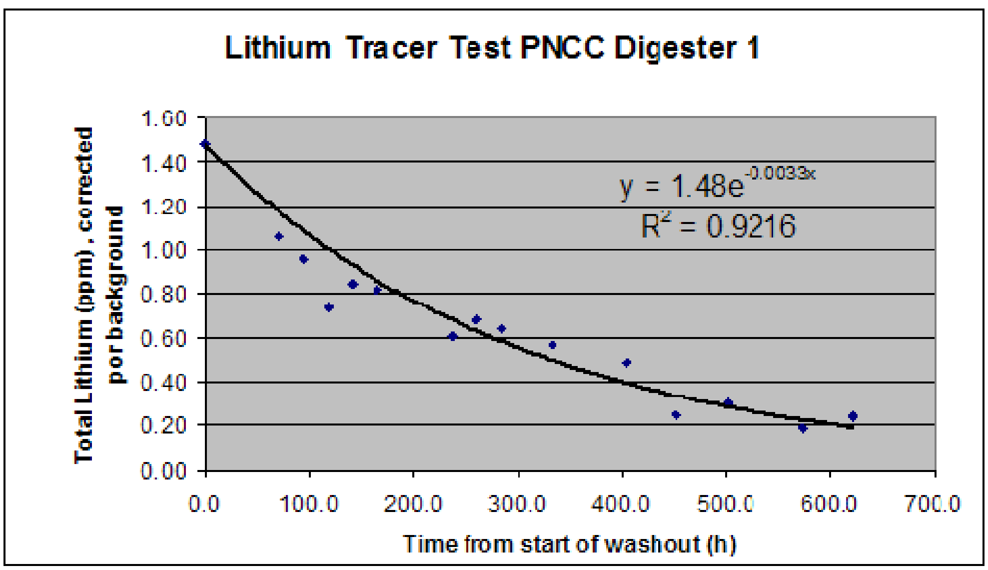


Figure 5: Lithium tracer mixing test in washout phase operation of the PNCC digester 1. Lithium background levels are subtracted from the presented data.



The kinetic curve fit in Figure 5 suggested an effective hydraulic residence time of 13.2 days in digester 1 whereas the expected nominal hydraulic residence based on the actual feed rate and nominal was calculated as 24.2 days. Thus 45 % of the digester tank volume was not well mixed during an observation period of 600 hours (25 days = 1 HRT) and did not effectively participate in the biogas production. Both tracer test methods revealed independently that the PNCC digesters were not well mixed. About 40-45 % of the nominal digester working volume did not effectively participate in the biogas production.

In summary, the results of two independent digester tracer tests showed that the PNCC WWTP digester mixing suffered from an inadequate mixing energy distribution leading to stagnant zones, preferential flow paths, flow short circuiting and sludge sedimentation whereas the total applied daily mixing energy was adequate (about 10 $W.\ m^{-3}_{digester\ working\ volume}$). Therefore a low cost, simple digester mixing upgrade through mixing energy redistribution was recommended. It was concluded that this was adequate to mix the total digester working volume and therefore practically double the treatment capacity of the digester tank at less than 5 % of the costs for a new digester tank.

2.1.3 STRATEGY FOR CODIGESTION OF TRADE WASTE

Stage 1 – mixing system upgrade in both digesters: With sufficient feedstock material of primary sludge quality or equivalent trade waste materials available (i.e. flotation foams, grease trap waste etc.) and an improved mixing energy distribution the daily biogas production could be 2.4 fold increased from currently 1,700-1,800 m^3/day (about 45 m^3 methane/hour) to about 4,250- 4,500 m^3 biogas/day (about 120 m^3 methane/hour from 2 digesters). This increase to 2/3 of the target methane production (target of about 180 m^3 methane/hour from 2 digesters) was expected to show no negative consequences on the digester stability because it solely relied on the full use of the constructed digester volume which was underutilized .

Stage 2 – implementation of booster technology in both digesters: At an achieved capacity of 120 m^3 methane/hour with the mixing system upgrade alone, stage 1 would produce a shortfall of 60 m^3 methane/hour for the final digester facility generator fuel target of 180 m^3 methane/hour. Booster technology is based on digester effluent treatment in a subsequent recuperative sludge thickening step (decanter centrifuge, screw thickener, table thickener, belt thickener etc.). This allows return of a pre-thickened very active anaerobic digester sludge into the digester. With a higher sludge capture, the digester can be safely operated at shorter hydraulic residence times (less than 10 days) and longer solids residence times (> 20 days) because the anaerobic sludge washout is counteracted by the recuperative digester sludge thickening.

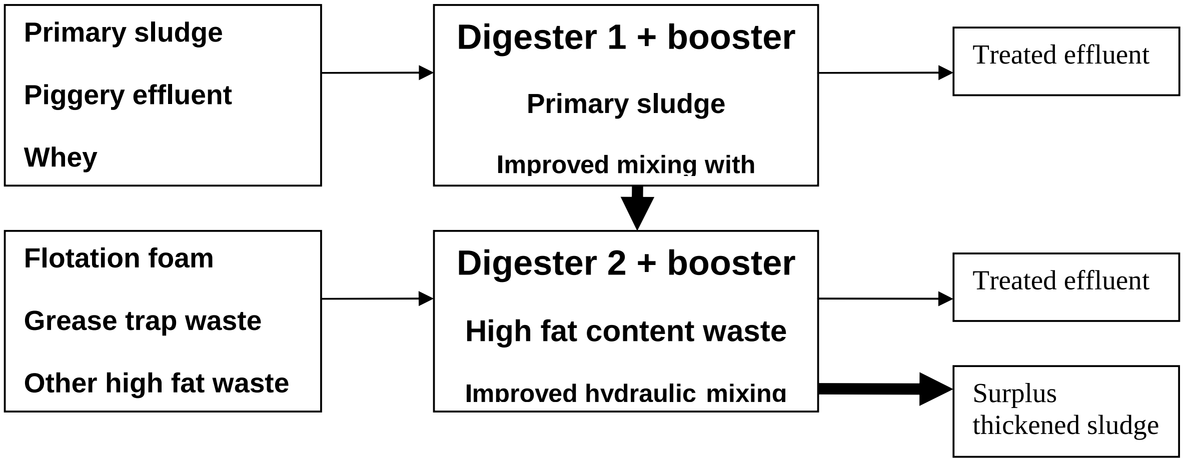
Booster technology allows also to effectively digest feedstocks with high contents of fat, oil and grease. Typically over 90 % fat digestion efficiency is achieved. Previous NZ research on the anaerobic digestion of concentrated fat materials (Broughton et al., 1998) has shown that fat build-up can lead to digester inhibition by production of bacteriotoxic long chain fatty acids (soaps). Booster technology prevents the build-up of soaps in properly operated digesters for trade waste with high contents of fat, oil and grease (FOG). This technology was applied in the Waste Solutions designed large co-digestion facility in Sydney (Thiele, 2000; Hearn and Thiele, 2004) and allows to effectively digest feedstock materials with fat contents in excess of 30-40 % fat, oil and grease in the feed material volatile solids.

The analysis of the expected composition of the regionally potentially available trade waste materials for PNCC WWTP co-digestion facility showed that the average digester composition needed for a baseline production of 180 m^3 methane/hour has a fat content of at least 31 % fat, oil and grease in the feed material volatile solids (data not shown).

Digester facility operation risks: Avoidance of any negative effects of co-digestion on the WWTP performance was a key consideration for the implementation. Only trade waste materials that are liquids/slurries and are free of materials that interfere with the proper functioning of the digester process are accepted. Figure 6 below summarizes the arrangement and best practices to give the upgraded PNCC digesters an increased baseline biogas productivity of up to 180 m^3 methane/hour with minimized operation risk.

Digester 1 is dedicated to primary sludge (PS) stabilization. Fitted with hydraulic mixing, gas recirculation mixing and a booster step it provides more operational security for primary sludge digestion in one tank than in the previous two sludge digester tanks without booster and hydraulic mixing. In case of a digestion inhibition in digester 1 due to an inferior primary sludge, the sequential arrangement and booster technology in both digester tanks provides a 3-4 fold increased treatment capacity security for PS stabilization in both tanks and thus reduced operation risk when compared to the previous status. The co-digestion scheme shown is designed to prioritize primary sludge stabilization over maximum methane production. Natural gas is permanently provided as back-up fuel guaranteeing the digester heating if primary sludge contaminants effect the digester performance. The acceptance and co-digestion of trade waste can be temporarily stopped to provide digester 2 for continued primary sludge digestion while digester 1 recovers.

Figure 6: Best practice arrangements of digester facility unit operations to optimize biogas yield and digester stability.



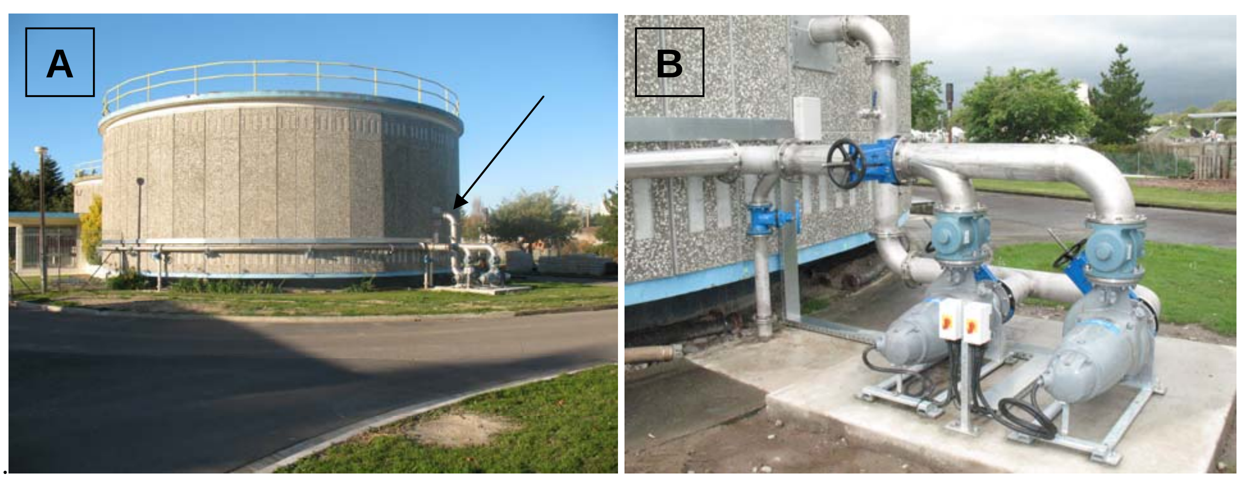
2.2 PRACTICAL DIGESTER MIXING SYSTEM UPGRADE OPTIONS

Based on a concept design and detailed design provided by CPG, PNCC installed new hydraulic digester mixing systems in digester 1 and digester 2.. The hydraulic mixing system (separate for each digester tank) is powered by a set of two new 15 KW sludge recirculation pumps (duty and standby), achieves mixed liquor rotation and produces about 4 mixed liquor turnovers per day. The use of the existing biogas recirculation mixing in this configuration is optional and can be discontinued to minimize foam formation when high fat waste materials are digested. The hydraulic mixing system is thus ideal for digestion of waste materials with high contents of fat, oil and grease and replaces the previous biogas recirculation mixing system. The construction and implementation costs were less than 220,000 $, additional operating costs are insignificant because operation of the new 15 KW sludge recirculation pump replaces most of the power use by the existing biogas blower.

Figure 7: Installed hydraulic mixing system upgrade to PNCC digester No 2 (D2) for co-digestion of primary sludge, grease trap waste, whey waste, Dairy DAF sludge and piggery manure.

A: New mixed liquor recirculation ring main with mixed liquor off take (arrow) and re-injection to create a horizontal and vertical rotating digester liquor movement.

B: Details of the mixed liquor recirculation pump system (about 300 m^3/h for each pump)



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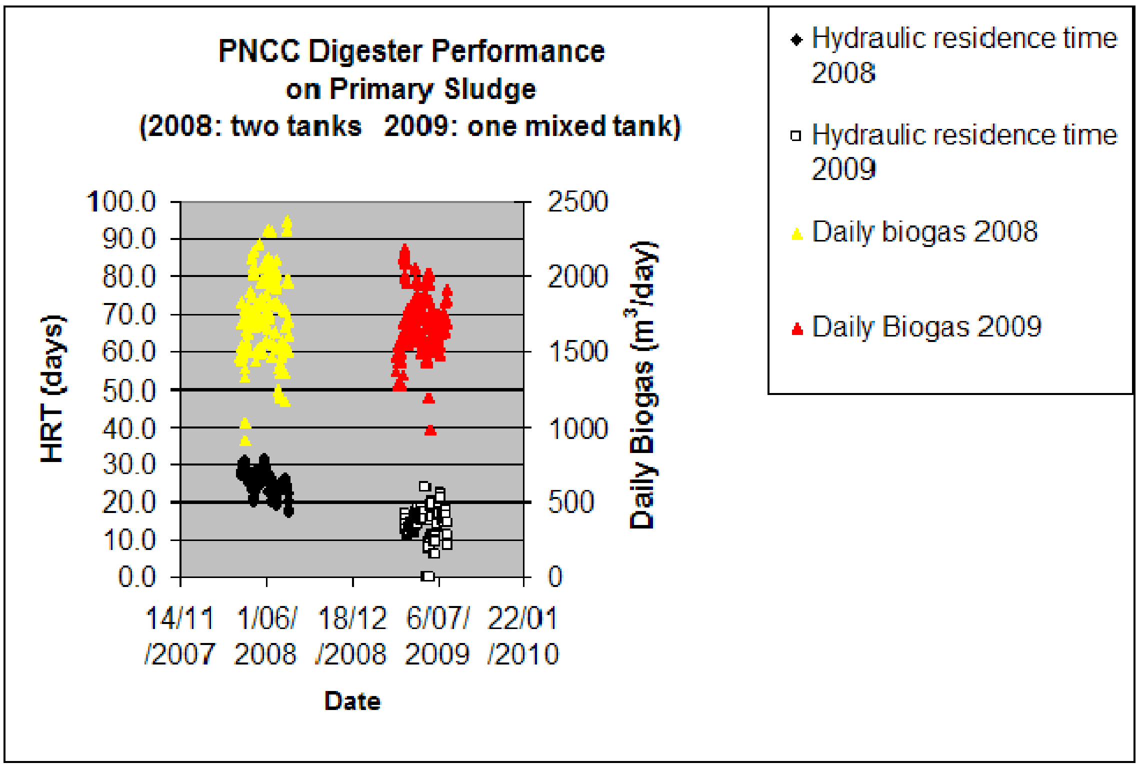
2.3 PRACTICAL RESULTS

2.3.1 EFFECTIVE PRIMARY SLUDGE DIGESTION AT < 15 DAYS HRT

The Lithium tracer test presented in Figure 5 demonstrated that dead zones and poor mixing in the PNCC digesters caused an effective combined HRT in both digesters of only of 13.2 days under normal operation conditions despite a nominal combined HRT of 20-30 days. Both digesters achieved good primary sludge degradation under these partially mixed conditions. Therefore it was concluded that digestion of the full daily PNCC primary sludge load should be feasible in a single well mixed digester tank when operated at 13-15 days HRT. Digester 2 was taken out of commission in April 2009 and the full PNCC primary sludge load digested by digester 1 with an upgraded temporary biogas recirculation mixing system to achieve full mixing. The actual daily primary sludge flow and biogas production data were compared for the period April – July 2008 (2 tanks) and April July 2009 (1 mixed tank) . The results are shown in Figure 8.

Figure 8: Comparison of PNCC WWTP primary sludge daily biogas production from two inefficiently mixed digester tanks (2008, yellow) with the biogas production from one well mixed digester tank (2009, red).



2.3.2 SMOOTH IMPLEMENTATION WITHOUT INTERRUPTION OF DIGESTER OPERATION

Municipal wastewater treatment plants need to perform to expectations on a continuous basis. It is therefore crucial that any measures needed for maintenance or the digester tank upgrades can be implemented without significant interruption of normal operations (n + 1 redundancy). The unique digester process arrangement shown in Figure 6 make such a smooth implementation feasible. Installation of the improved biogas recirculation system in digester 1 required diversion of the full daily primary sludge load to digester 2 only for about one week. After that, digester 1 was suitably equipped to effectively accept the full daily primary sludge load (see Figure 8). To “err on the side of caution”, a gradual load shift of the whole primary sludge load into digester 1 was executed over a 6 week period in February/March 2009. After that period, digester 2 could be taken out of operation for clean-out and retrofit with an improved hydraulic mixing system without affecting gas production and sludge treatment efficiency of the PNCC WWTP (Figure 8).

2.3.3 VALIDATION OF THE MIXING SYSTEM IMPROVEMENT

Good mixing is essential in municipal sludge digesters mainly for three key tasks

(1) Even heat distribution to keep the digester at uniform and appropriate temperature

(2) effective contact between the fresh sludge material and the resident active anaerobic sludge/alkalinity buffer to promote biogas production and to prevent formation of acidic mixed liquor zones/pockets

(3) prevention of sludge settling

Table 1 summarizes the key digester performance indicators when operated on primary sludge during various stage of the mixing system upgrade.

Table 1: Summary of key digester performance indicators when operated on primary sludge during various stage of the mixing system upgrade. Note the improved daily biogas production, digester mixed liquor pH and digester mixed liquor alkalinity when the digesters were operated with the new hydraulic mixing system. The digester operating temperature was identical in all cases and close to 36^{o}C. N/A: data not available due to uncertainty with the biogas flow measurements.

Operation Condition	**Nominal HRT (days)**	**pH**	**Volatile fatty acids (mg/L)**	**Alkalinity (mg $CaCO_3$/L)**	**Mixed liquor solids (%)**	**Biogas production (m^3/day) (For full primary sludge load equivalent)**
Before upgrade: Apr-Jul 08 – old biogas mixing system (D1 +D2)	25+/- 3	6.8 +/- 0.06	10-30	1500 +/- 200	1.44 +/- 0.25	1710+/- 280
Stage I: Apr-Jul 2009 – improved biogas mixing system (D1)	15+/- 4	6.8 +/- 0.08	10-20	1500 +/- 200	1.27+/- 0.25	1670+/- 200
Stage II: Jan - Mar 2010 – improved biogas mixing system (D1)	25+/- 3	6.7 +/- 0.05	20-30	1530 +/- 110	1.40 +/- 0.19	N/A
Stage II: Jan - Feb 2010 – new hydraulic mixing system (D2)	25+/- 3	7.0 +/- 0.07	23+/- 15	2150+/- 180	1.52 +/- 0.11	N/A
Stage II: Feb - Mar 2010 – new hydraulic mixing system in D2 with added 10 % Dairy DAF sludge (see figure 2 for details)	23 +/- 3	7.0 +/- 0.07	35+/- 20	2225+/- 170	1.52 +/- 0.15	3300-3400 m^3/d digester gas expected when both digesters are loaded with primary sludge PLUS dairy DAF sludge (prelim. data, additional 20 % of the daily primary sludge flow as dairy processing DAF sludge).

In the period prior to the digester upgrade the digester mixed liquor solids content was 1.44 +/- 0.25 % solids with an alkalinity of about 1500 mg/L ($CaCO_3$ equivalents) and volatile fatty acid (VFA) levels of 10-20 mg/L. The nominal HRT was 25+/- 3 days and the mixed liquor pH was about 6.7-6.8.

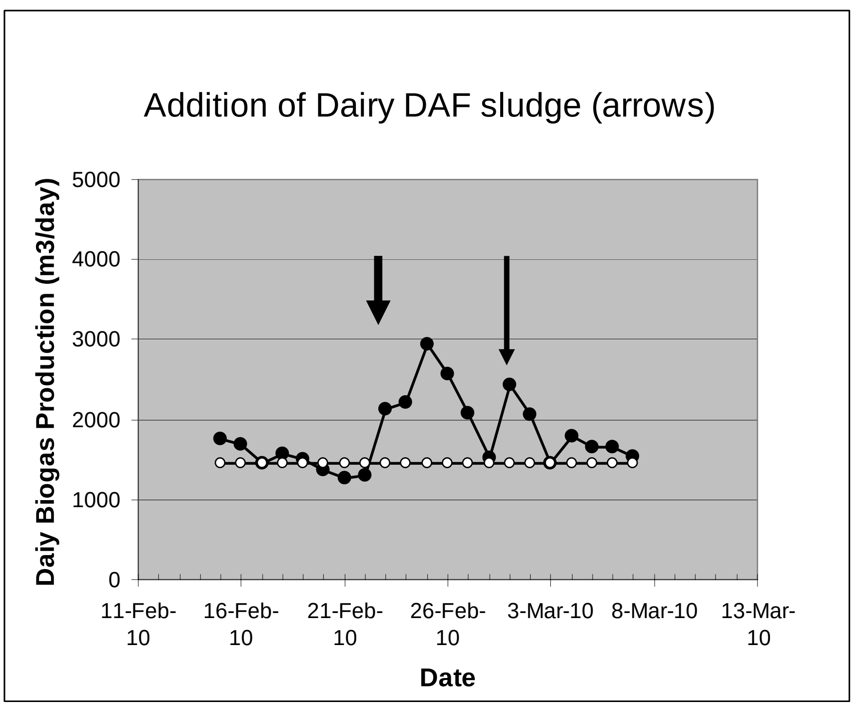
In stage I of the upgrade, digester D1 (fitted with an improved biogas recirculation mixing system) treated the full primary sludge (PS) flow of 110 m^3/day and produced virtually the same key digester performance indicators as before but at an HRT of 15+/- 4 days.

In the period January to March 2010 (stage II), digester D1 was compared side by side with digester D2 with the new hydraulic mixing system for more than 3 HRT, each receiving 50 % of the total PNCC PS load (about 55 m^3/day per digester tank). The digester D1 at 25+/- 3 days HRT (Table 1, stage II) produced practically the same key performance indicator values as during stage I in April to July 2009 when operated at 15+/- 4 days HRT (Table 1, stage I). This result demonstrated that the digestion of primary sludge in a well mixed digester was already complete at 15+/- 4 days. Increasing the digester D1 HRT to 25+/- 3 days did not further reduce the mixed liquor solids content or increase the daily biogas production, pH or alkalinity.

In order to further validate the efficiency of the digester D2 upgrade with the hydraulic mixing system, dairy processing wastewater DAF sludge was selectively added to digester 2 for one month while receiving also ½ of the total PNCC PS load (Figure 9). A total of 164 m^3 of dairy processing DAF sludge were loaded to digester 2 representing about 10 % of the total volumetric load with primary sludge in this period. The strength of the incoming DAF sludge was not continuously monitored. From experience, the solids content would be between 10 - 15 % total solids and the fat content about 6-10 % (wet basis) of the loaded DAF sludge.

Figure 9: Rapid response time of PNCC digester system biogas production when small amounts of Dairy Processing sludge from Dissolved Air flotation (DAF) wastewater treatment were added to the hydraulically mixed digester D2. Both PNCC digester tanks (D1 and D2) were equally loaded during this period with PNCC primary sludge (55 +/- 10 m^3/day per tank, 4 % TS). Where indicated by the arrows, small amounts of additional Dairy DAF sludge were added to the primary sludge load to digester D2 only for a period of about 4 days each. The line with the open symbols represents the 4 year (2006-2009) daily biogas production average from primary sludge digestion (D1 + D2) at the PNCC WWTP in the months February and March.

: approx. 20 % of inflow to D2 as Dairy DAF sludge; : approx. 10 % of total inflow to D2 as DAF sludge



Despite the significantly increased organic loading rate to digester D2 with the added DAF sludge, the hydraulically mixed digester system responded rapidly to the DAF sludge addition (Figure 9). Foam or fat layers did not build up in the tank , the total VFA levels remained below 40 mg/L (Table 1, stage II) and the key performance indicators in the mixed digester liquor were virtually indistinguishable from the digester D2 operation with primary sludge alone (Table 1, stage II).

The added biogas yield in the period 23 February – 28 March 2010 resulting from dairy DAF sludge addition to digester D2 was determined by subtracting the four year average combined PNCC Totara road digester daily biogas production in the months February/March from the combined PNCC Totara road digester daily average biogas production in February/March 2010. More than 400 m^3/day additional biogas were formed for one month on average in the hydraulically mixed digester tank (D2) when receiving 10 % additional DAF sludge.

This result therefore confirmed and validated the expected daily digester gas production improvement potential from co-digestion of primary sludge and added selected agro-industrial co-substrate waste.

2.4 KEY CONSIDERATION FOR INCREASING THE GAS OUTPUT

The results in Table 1 were consistent with the international experience on co-digestion of primary sludge and selected co-substrate waste materials. However, the achievable daily biogas production through traditional co-digestion approaches (Figure 8) corresponds to an average hourly methane production of about 90 – 100 m^3 methane/hour and thus falls short of the PNCC digester gas production target of more than 180 m^3 methane/hour.

CPG proposed thus to add recuperative sludge thickening (booster technology) to both PNCC digesters after the mixing system upgrade This step allowed to thicken the anaerobic sludge in the digester effluent and by returning the thickened sludge into the digesters added the capacity to increase the mixed liquor in the digester tanks from 1,5 % total solids content (Table 1) to more than 3 %. As a byproduct, this doubled the active anaerobic bacteria sludge concentration and active anaerobic sludge mass in the PNCC digesters allowing to double the loading rate and the digester gas production. As additional benefit, the “sludge age” of the anaerobic sludge in the digesters is also doubled.

2.5 CO-DIGESTION WITH BOOSTER TECHNOLOGY INSTALLED

Figure 10 below gives a general outline of the co-digestion process design model developed by CPG to fit anaerobic co-digestion processes into existing sludge digesters with and without booster step. This model is suitable to be applied to any WWTP. The digester processes with recuperative thickening are suitable for co-digestion of municipal biosolids and selected agro-industrial waste materials in well mixed digester tanks. The mass balance process model of CPG is very flexible and can be applied to any co-substrate waste mixture and any municipal and industrial sludge digester facility. This model was used for the design of the recuperative thickening/digester booster process for the PNCC digester upgrade.

The installation of a new recuperative thickener facility at the PNCC WWTP was completed in March 2012 It is automated and consists of a drum thickener with polymer dosing system and adequate sludge pumping facilities. Initially it was connected to PNCC Totara Road WWTP digester 2. The facility is sized for a anaerobic digester mixed liquor throughput of 1000 kg DS/hour and is thus sized to service both PNCC digesters (total digester working volume 2,700 m^3)

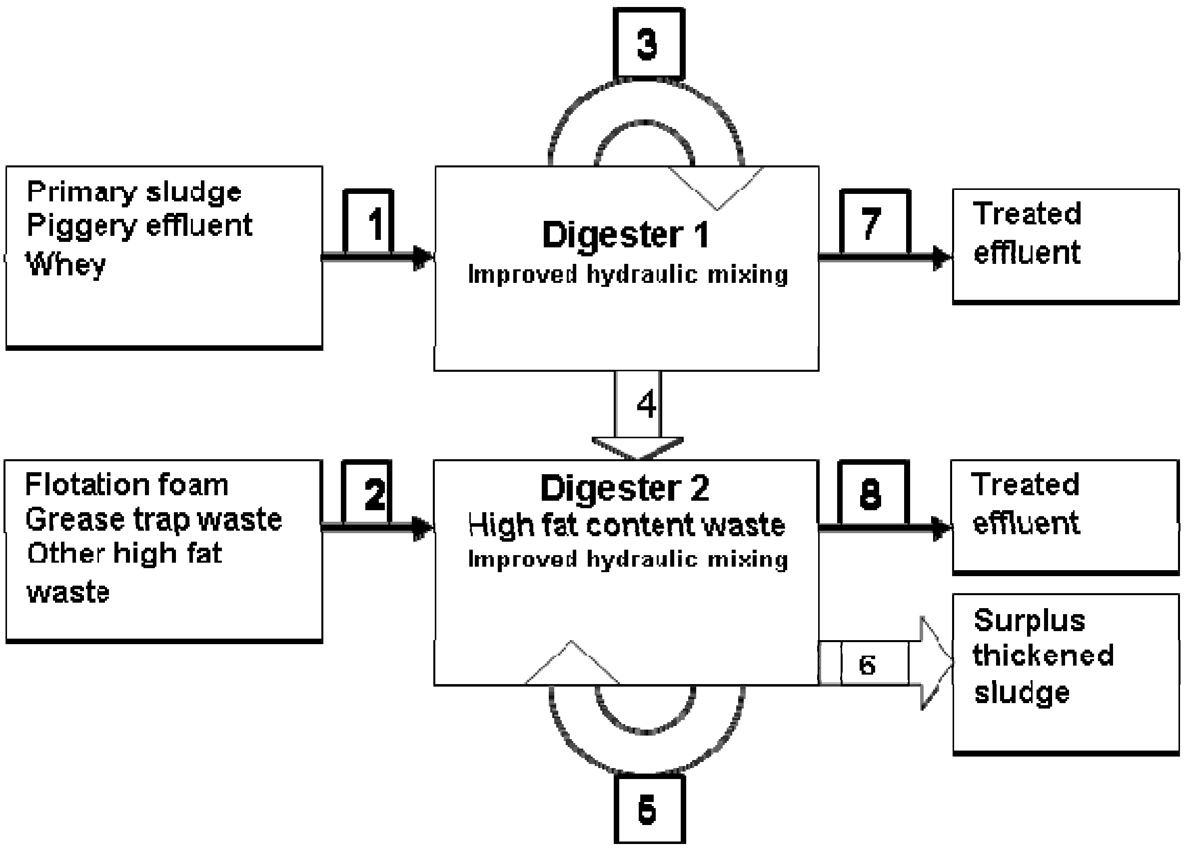
Initial performance testing of the digester 2 operation with booster connected showed that the mixed liquor suspended solids concentration can be increased within a 30 day period to about 2.5 % TSS by recuperative thickening.

Recuperative thickening had no negative effects on the digester stability and anaerobic sludge activity. The methane producing activity of the resident anaerobic digester sludge was 0.15 kg methane COD/kg_{VSS}/day before and after connection of the recuperative thickening step whereas the methane producing activity of the resident anaerobic digester sludge was only 0.07 kg methane COD/kg_{VSS}/day when tested before the PNCC digester upgrade. This demonstrated that the upgrade had not only doubled the digester biomass concentration but also doubled in addition the specific activity of the resident bacteria under co-digestion conditions with dairy factory DAF sludge with a high content of FOG (fat, oil and grease).

Total VFA levels in the digester 2 mixed liquor when digestion primary sludge and dairy factory DAF waste with operating recuperative thickening were maintained close to the detection limits of the analytical technique When dairy industry DAF sludge trade waste was daily dosed over several months into digester 2 operated with primary sludge as main feedstock, a 3 fold increased biogas production rate of up to 2,600 m^3 biogas/day was observed in the digester with trade waste when compared to the previous gas production without dairy factory DAF sludge co-digestion (850 m^3 biogas/day). As the total VFA levels remained low during that period CPG conclude that further daily gas production increases are possible by feeding additional trade waste materials to this digester.

Figure 10: Outline of the process steps included in the mass balanced co-digestion model. Input materials are specified as daily load (t/day wet), total solids content (%TS), volatile solids content (% VS in TS), nitrogen content (TKN; mg/L) and fat, oil and grease content (FOG, mg/L). Outputs are the expected daily biogas production from each digester and the flow and composition of treated effluent and surplus thickened sludge.

Recuperative sludge thickening flows 3 and 5 of the drum thickener are variable and user programmable as well as the transfer of thickened digester sludge from digester 1 to digester 2.



2.6 PRELIMINARY COST/BENEFIT ANALYSIS

The actual operation performance data presented above have demonstrated that stage 1 and stage 2 of the digester facility upgrade has created at least a 200 % increased treatment capacity at the PNCC sludge digesters. With capital costs for the stage 1 upgrade of less than 700,000 $ (digester 1 and digester 2), this process oriented digester facility upgrade has allowed to defer the construction of one new 1,350 m^3 digester tank system. Based on current market prices of around 1,100 $/$m^3$ for modern municipal sludge digesters at this scale, the digester process and mixing upgrade investment of 640,000 $ has substituted a capital asset purchase in the order of 1.5 million $. With expected revenues from biogas sales for additional biogas on top of the digester plant boiler requirements of 85,000 $/annum as genset fuel (@ 2.6 c/kwh biogas; 7.2 NZ$/GJ) and gate fee revenues of 220,000 NZ#/annum for co-digestion of about 20 t/day of selected trade waste materials, the payback period for the stage 1 upgrade (no booster installed) is in the order of 2.1 years (Table 2, below) This result demonstrates the cost effectiveness of the strategy and design that CPG has developed and demonstrated with the PNCC digester mixing upgrade in stage 1. The upgrade of digester 1 and digester 2 with modern hydraulic mixing enabled PNCC also to receive and digest high fat content trade waste and collect additional gate fee income for the treatment of additional industrial and trade waste.

Similar economic considerations apply to the upgrade in stage 2. Total expected capital costs of about 1,200,000 $ (+20 %, - 10 %) for the complete mixing upgrade, waste reception facility and one booster module installed and connected to both digester tanks are expected to increase the trade waste specific biogas production capacity from 1,400 m^3 biogas . day^{-1} (stage 1) to about 4,600 $m^3.day^{-1}$ (stage 2) with additionally 1,700 m^3/day biogas from the primary sludge digestion.

Thus in combination, the stage 1 and stage 2 digester upgrades create capital assets that are equivalent to a value of 3 million $ digester plant installations at actual costs of about 1,200,000 $. The municipal digester plant upgrade strategy to a modern co-digestion facility proposed, designed and tested by CPG and implemented by PNCC is thus a very cost effective measure and could be applicable to many different municipal digester plants in New Zealand and Australia.

Table 2 summarises the expected costs and benefits for the upgrade of municipal sludge digesters into a commercial co-digestion facility for concentrated liquid trade waste from commercial, agro-industrial and municipal sources. The digester capacity when fully utilised is rated for processing of about 50 t/day high fat content biodegradable concentrated trade waste (grease trap waste, DAF sludge, whey) in addition to about 130 t/d of WWTP primary sludge. With an estimated projected gross revenue of 670,000 $/annum (+10 %/ - 20 % uncertainty), the total upgrade to trade waste co-digestion is expected to achieve a simply payback period of less than 2 years for an initial capital outlay of approximately 1,200,000 $NZ (Table 2).

Table 2: Preliminary cost /benefit analysis for the expected performance of a municipal sludge digester upgrade to a co-digestion facility with booster. The biogas production is estimated for a range of available feedstock materials (data not shown) using the technical biogas yield that is typically achievable with these materials (uncertainty + 10 % / - 20 %). The gate fee is estimated as the differential between the avoided landfilling costs and the additional operating costs for waste collection, transport and reception at the co-digestion facility.

Upgrade stage	Digester tank	Capital cost estimates (NZ$)	Additional Biogas (kwh/day)	Additional biogas value (NZ$/annum)	Waste processed (t wet /annum)	Gate fee (30 $/t) (NZ$/ annum)	Polymer costs (6 kg/t DS, 9 $/t wet)
Stage 1	**Dig 1**	**220,000**	**0**	**0**	**0**	**0**	**0**
	Dig 2 + waste reception	**220,000 +200,000**	**9,000**	**85,000**	**7,300**	**220,000**	**0**
Total stage 1: (8 months)		**640,000**	**9,000**	**85,000**	**7,300**	**220,000**	**0**
Stage 2	**Dig 1**	**275,000**	**9,000**	**85,000**	**7,300**	**220,000**	**66,000**
	Dig 2	**275,000**	**21,000**	**200,000**	**11,000**	**330,000**	**99,000**
Total upgrade:		**1,190,000**	**30,000**	**285,000**	**18,300**	**550,000**	**(165,000)**

2.6.1 CHALLENGES FACED/LESSONS LEARNT

Technical challenges: There were only minor technical challenges in this digester upgrade project. The digester upgrade proceeded smoothly without major technical complications. Installation and commissioning of mixing system upgrades was achieved within a 2-3 month period for each digester tank. Operating the WWTP digester on primary sludge with only one digester tank operating for 2-3 months proved to be without technical risk. The operation of the upgraded mixing system was simple with practically no added daily work for the WWTP operators.

The operation of the waste reception facility for liquid waste from commercial and industrial sources was effectively delegated to the liquid waste truck drivers during the unloading from the trucks into the storage tanks. The transfer of the daily delivered liquid waste from the storage tanks into the digesters was through actuating of dedicated pumps without significant time demand on the WWTP operators. Thus operating of a co-digestion digester for liquid trade waste can be easily integrated into the normal WWTP working routines.

A main technical challenge was the rapid onset of the increased biogas production when the trade waste material was delivered in an irregular pattern (Figure 9). This led to the "flaring" of substantial amounts of the produced biogas that otherwise would have been available for genset operation and electricity production. The management of a more regular trade waste supply and adjustment for seasonal effects needs thus to be a focus for the management of a trade waste co-digestion facility in a municipal digester plant.

The recuperative thickener installation and commissioning has only been completed in April 2012. Therefore it is too early to report in detail about this operation. To date there have been no significant problems with this part of the operation and the routine recuperative thickening of anaerobic digester sludge with drum thickeners is practiced elsewhere without technical complications.

Thus, a digester upgrade to co-digestion of liquid trade waste is technically manageable within the capabilities of the normal operation of a municipal sludge digester plant.

Commercial challenges: A major commercial challenge in the start-up of this co-digestion facility was the need to minimize the use of natural gas for genset operation in the start-up period. As natural gas prices are typically increasing over time, the future costs of natural gas use in the 1st year of co-digestion facility operation need to be established/estimated before initiation of the digester plant upgrade project.

Achievement of a minimum natural gas use depends specifically on the choice of the genset size and the matching establishment of firm longterm contracts for the supply of suitable trade waste materials to match that chosen genset module size.

While the anaerobic digesters with recuperative thickening can receive a wide range of different trade waste materials and in irregular patterns, it is especially important that the daily load of digestible matter (daily load of degradable COD; Figure 9). is balanced within a +/- 20 % bandwidth (trade waste biodegradable COD, kg COD/day) if a +/- 10 % variability of the daily biogas production is the commercial target. It is expected that the variability in volume and consistency of the daily trade waste deliveries will decrease within the 1st year of co-digestion operation as new waste material types and suppliers are coming on stream (law of averages).

3 CONCLUSIONS

The CPG designed municipal sludge digester upgrade approach technology for co-digestion of primary sludge and selected agro-industrial waste materials has been successfully completed and validated at the PNCC Totara Road plant. The actual operation data after the upgrade show that digester clean-out and upgrade with a modern hydraulic digester mixing system and co-digestion of selected trade waste material at least doubles the daily digester gas production of the existing digester tanks.

Extensive digester process design, modeling work and actual implementation have shown that further biogas production improvements are technically feasible through the use of (a) additional biodegradable trade waste materials, (b) addition of recuperative sludge thickening of the digester effluent and (c) and return of the active anaerobic digester sludge (booster step technology) into the sludge digesters. A recuperative thickening facility using drum thickener technology has been constructed for the PNCC digesters and commissioned. Subject to availability and successful sourcing of suitable selected trade waste materials the complete digester upgrade of two existing digester tanks is expected to produce an annual biogas output in the order of 7,000 m^3/day from a digester volume of 2,700 m^3 (2.6 V biogas/$V_{digester}$/day).

The innovative digester upgrade technology has thus created the additional digester gas production capacity of 2 new additional new digester tanks at a fraction of the equivalent capital costs for one new tank. The payback period for the combined stage 1 and stage 2 upgrade is estimated to be less than 2 years simple payback period assuming achieved average gate fees of 30 $/t trade waste processed and biogas sales at 7.2 NZ$/GJ.

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REFERENCES

Al Seadi, T. (2000). Danish Centralised Biogas Plants – Plant Descriptions. Bioenergy Department, University of Southern Demark, Torben Skott, BioPress.

M J Broughton, J H Thiele, E J Birch, and A Cohen (1998). Anaerobic batch digestion of tallow. *Water Research* 32 (5): 1423-1428.

Hearn, C. and Thiele, JH. (2004). Design and Implementation of a large Digester Facility for Putrescible Waste - Process Implementation and Lessons Learned. Proceedings of the 2004 Annual Conference of the NZ Waste Management Institute. Auckland, 9-11 November 2004.

Thiele, J H (2000) Biowaste processing - resource recovery from putrescible solid and liquid waste. Conference proceedings of the Annual Conference of the Waste Management Institute of New Zealand, Auckland 1-3 November 2000.

Thiele, J H (2009). Municipal sludge digester upgrade for biofuel production. Proceedings of the Water New Zealand Annual Conference. 23-25 September 2009. Energy Events Centre. Rotorua, New Zealand