# MUNICIPAL SLUDGE DIGESTER UPGRADE FOR BIOFUEL PRODUCTION

***Jürgen H Thiele***
***Waste Solutions, a Division of CPG (NZ) Ltd, Dunedin, New Zealand***

## ABSTRACT

A number of municipal wastewater treatment plants in New Zealand operate simple sludge digesters with floating roofs, biogas recirculation mixing, low volatile solids (VS) loads (about 1.5 kg VS. $m^{-3}_{digester}.day^{-1}$), long hydraulic residence times (15-25 days) and low biogas productivities (0.7 $m^3_{biogas}$. $m^{-3}_{digester}.day^{-1}$). Typically these digesters suffer from inefficient sludge: biomass contact, poorly mixed dead zones, flow short circuiting and consequential build-up of sediment.

Waste Solutions has successfully designed, constructed and commissioned a number of industrial sludge digesters with high organic loading rates (4 - 5 kg VS $m^{-3}_{digester}.day^{-1}$). These systems have the capability to process approximately 3 times the organic load of comparable municipal digesters because they are well mixed (mixing energy: 10-20 $W.m^{-3}_{digester}$) resulting in high biogas productivities (2 - 3 $m^3_{biogas}$. $m^{-3}_{digester}.day^{-1}$) and short hydraulic residence times (10-15 days).

Here we report a hydraulic residence time analysis for the Palmerston North Totara Road primary sludge digesters. We present the application of the analysis for a digester mixing upgrade with the ultimate objective to generate additional digester capacity for co-digestion of additional trade waste materials. A simple process model is used to determine the improved biogas production and digester facility operating costs. Actual digester operation records show that the mixing system upgrade achieves more than 100 % biofuel (biogas) output improvement and an expected payback period of less than 2 years. The full biogas production is used to operate a generator for production of renewable electricity. The generator waste heat is used for digester heating. This configuration allows to generate additional revenue through higher utilization of existing capital assets.

## KEYWORDS

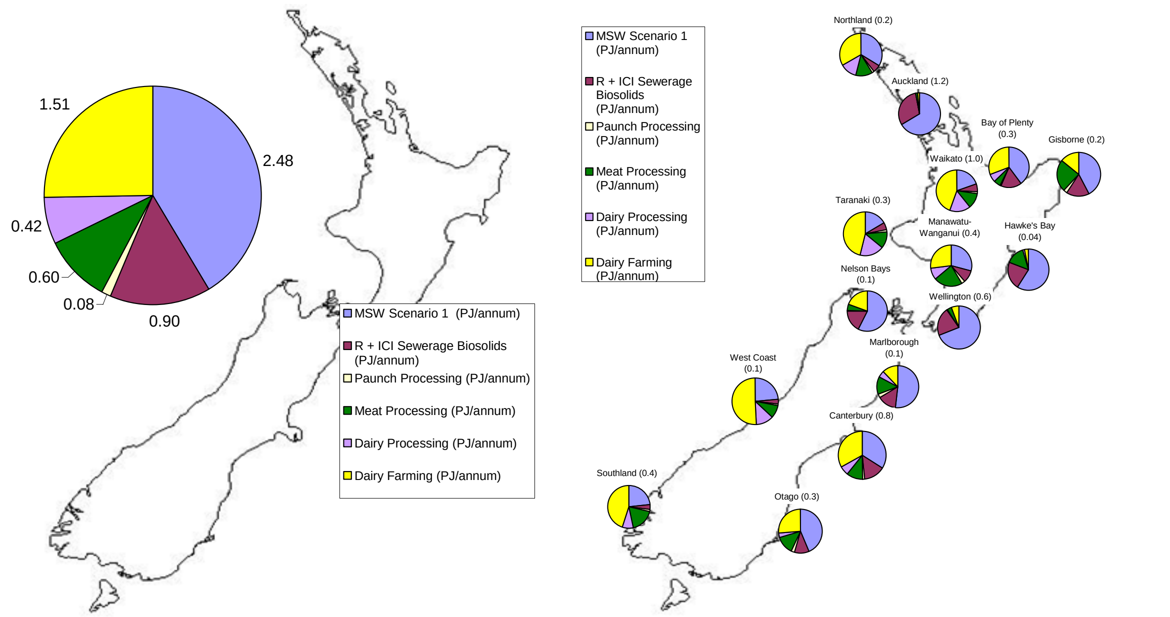
**Sludge digesters, trade waste, co-digestion, biofuel, cogeneration, regional digester facility**

## 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) and this leading examples has been widely followed throughout Europe and North America with combined digestion of industrial waste, manure and municipal biosolids in a large number of large regional municipal, agricultural and industrial digester facilities (Al Seadi, 2000).

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

**Figure 1:** NZ National usable End Energy Potential and regional biofuel distribution from 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 bioenergy 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, $N_2O$).

Waste Solutions 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 venturi mixing (Chapel Street Digesters, Tauranga) and have the capability to process approximately 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 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 digestion for the stabilization of wastewater biosolids such as primary sludge (PS) and secondary waste activated sludge (WAS). Often these municipal digesters were designed 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. Due to lower capital costs for a retrofit versus a new digester plant, this approach could realize lower gate fees for waste generators and thus be more cost effective and appropriate in the New Zealand context.

The Palmerston North City Council (PNCC) recently initiated 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 digestion at the WWTP and landfill gas recovered at the adjacent landfill. The current methane production at the WWTP digesters is about 45 $m^3$/hour whereas the generator requires a fuel gas flow equivalent to approximately 180 $m^3$ methane/hour for operation at full capacity. PNCC is thus currently investigating options for increasing methane production from the two anaerobic digesters at the WWTP. A recent regional trade waste and industrial byproduct availability survey in the greater Palmerston North region has been completed and identified availability of appropriate amounts of highly digestible feedstocks for co-digestion with the primary sludge from the WWTP.

In August 2008, PNCC invited Waste Solutions (WS), a division of CPG (NZ) Ltd, to conduct a site and digester plant inspection and to prepare a proposal how to improve the digester gas production and stability while digesting available supplementary digester feed for the purpose to meet the 180 $m^3$ methane/hour target. A technical strategy was developed with the client with the objective to minimize capital costs for the digester upgrade while maximizing the benefits from an improved biogas production. The proposal by WS suggested that a digester cleanout plus digester mixing efficiency improvement (stage 1) followed by installation of recuperative sludge recycle (booster technology, stage 2) could increase the current digester gas production about 3-4 fold if highly digestible trade waste feed stocks would become available on a consistent basis. This paper presents the strategy, the costs and the results of the realization of this plan at the PNCC WWTP.

# 2 RESULTS AND DISCUSSION

## 2.1 PNCC DIGESTER PLANT UPGRADE STRATEGY

### 2.1.1 ANALYSIS OF THE STATUS QUO

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. The WWTP staff have a good grip on the operation which has successfully continued for several decades.

**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.

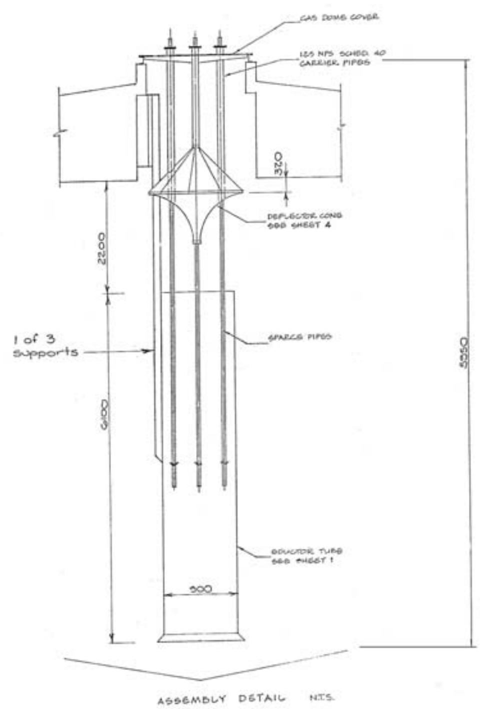
Pre-thickened primary sludge at 4 % total solids (TS) with about 70 % VS in TS is digested at a nominal hydraulic residence time of 22- 28 days. The achieved volatile solids reduction of 50-55 % and the biogas yield

(1.1 $m^3$/kg VS destroyed) are within expectation for primary sludge digestion. Volatile acid (VFA) levels and alkalinity in the digester mixed liquor are typically < 100 ppm and > 1800 ppm respectively indicating a stable digester operation. However, the biogas productivity of the PNCC sludge digesters (0.6 – 0.7 $m^3$. $m^{-3}_{digester}$) is low with only about 1/3rd of the productivity that is regularly achieved in industrial sludge digesters. This could indicate one of two things: (a) the daily load of digestible material is too low or (b), the digesters are insufficiently mixed achieving low contact between the anaerobic sludge and fresh feedstock.

### 2.1.2 REVIEW OF CURRENT DIGESTER MIXING LIMITATIONS

In September 2008 PNCC commissioned Waste Solutions for a review of the current digester operations and mixing system. The digesters are individually mixed by a dual system. Firstly, the mixed liquor is re-circulated by pumping through a heat exchanger mixing the digester 24 hours per day at a nominal rate of 3.5 W. $m^{-3}_{digester\ working\ volume}$. This system is effective but does not reach the recommended 10-20 W. $m^{-3}_{digester\ working\ volume}$ digester mixing energy. In addition, the biogas blower operates for 8 hours/day also a central eductor tube (Figure 3) with a nominal energy transmission of approximately 11 W. $m^{-3}_{digester\ working\ volume}$. Thus the dual mixing system supplies 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 is expected for 16 hours/day to lead to sludge settlement, limited mixing, limited waste : biomass contact and reduced heat supply to the active bacteria. An extension of the operation time for the biogas recirculation is not possible due to noise restrictions during night time.

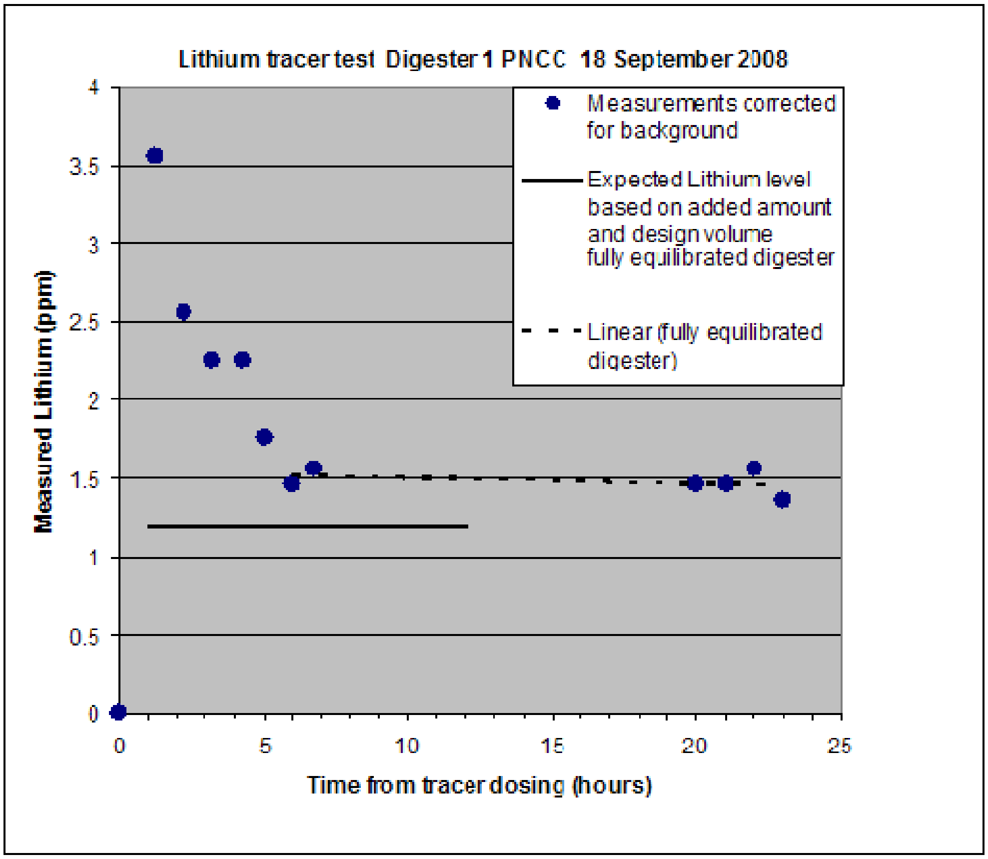
**Figure 3:** Central eductor tube and deflector cone in the current digester mixing system used to mix the digester and to splash/spread mixed liquor onto top of scum layer to reduce scum formation.



A potential secondary digester mixing issues was discovered in the review. Mixing with the central eductor tube mixer with deflector cone would possible radially penetrate only a few meters from the centre leaving a large peripheral proportion of the digester working volume virtually “under mixed”. PNCC commissioned therefore WS in September 2008 to conduct a digester mixing performance test using the well proven Lithium tracer test.

In short, the test consists of two phases – a batch phase and a washout phase. During the batch phase the hydraulic mixing and biogas recirculation mixing were both kept running for 12 hours and digester feeding was stopped. A slug dose of 10,000 g LiCl dissolved in 4 $m^3$ of warm water was pumped into digester 1 over 15 minutes while hydraulic mixing and biogas recirculation mixing were both kept running for 12 hours and digester 1 feeding was stopped. The tracer distribution kinetics in the mixed liquor were monitored at one sampling point. Samples were taken from the digester 1 mixed liquor recirculation loop. Hourly samples were analyzed by ICP mass spectrometry and the background Lithium content of the sludge was subtracted. The Lithium background level of the PNCC digester sludge was 0.14 ppm. The Lithium tracer recovery was > 97 %. The results are shown in Figure 4.

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




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

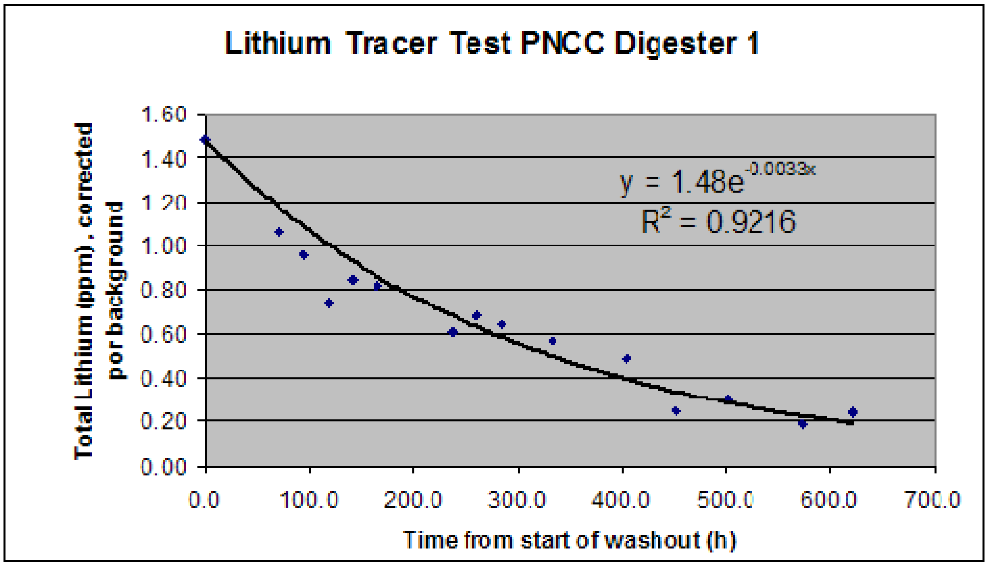
After completion of the batch test with the Lithium tracer equally distributed (Figure 4), the digester 1 was then operated with the normal daily primary sludge loading under routine continuous operation regimes. This caused the added Lithium tracer to be continuously washed out with fresh primary sludge (average Lithium background in PNCC primary sludge: 0.14 ppm). Mixed liquor samples were daily taken from the digester mixed liquor recirculation loop. This test measures with a first order kinetic fit (Figure 5) the effectively mixed working volume in the digester by calculating the effective hydraulic residence time ($HRT_{EFFECTIVE}$) in the examined digester tank.

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




Both tracer tests revealed that the PNCC digesters are not well mixed. About 40-45 % of the nominal digester working volume does not effectively participate in the biogas production. The kinetic reaction fit in Figure 5 suggests 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 participate in the biogas production.

Practically the same result was obtained from the batch test (Figure 4). The Lithium concentration in the early mixed liquor samples reached about 3 ppm and thus double of the equilibrated level after 24 hours despite the biogas recirculation system and the hydraulic mixing system operating together for 12 hours at full capacity during the batch test. The initial high Lithium concentrations in the mixed liquor show that in the first 2-3 hours about 50 % of the digester working volume were basically bypassed by the recirculation flow and poorly mixed.

In summary, the results of two independent digester tracer test with two different underlying working principles have consistently shown that the PNCC WWTP digester mixing suffers from an inadequate mixing energy distribution leading potentially to unmixed dead zones, preferential flow paths, flow short circuiting and sludge sedimentation whereas the total applied daily mixing energy is adequate (about 10 W. $m^{-3}_{\text{digester working volume}}$). Therefore Waste Solutions (WS) recommended a low cost, simple digester mixing upgrade through mixing energy redistribution and installation of a limited amount of additional biogas injection lances at the tank periphery. 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 (see section 2.3) at less than 5 % of the costs for a new digester tank.

The Lithium tracer data from the batch test also suggested that about 15-20 % of the digester working volume (difference between dotted line and solid line in Figure 4) are filled with settled sludge. WS thus recommended to conduct a thorough digester tank clean-out - additionally to the recommended mixing system upgrade – in order to remove all sediment and further increase the digester treatment capacity by about 20-25 %.

### 2.1.3 KEY STRATEGIES TO ACHIEVE IMPROVED METHANE PRODUCTION

**Stage 1 – mixing system upgrade in both digesters:** The results shown in section 2.1.2 demonstrated that an effective mixing system upgrade by improved mixing energy distribution combined with a digester tank sediment cleanout is expected to achieve a 2.5 fold increase of the primary sludge treatment capacity in the PNCC WWTP sludge digesters. With sufficient feedstock material of primary sludge quality or equivalent available (i.e. flotation foams, piggery effluent etc.) this increases the digester biogas production 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). This increase was expected to show no negative consequences on the digester stability because it solely relies on the full use of the constructed digester volume which is currently underutilized.

The mixing system upgrade constitutes stage 1 of the recommended path to improved methane production. The digester mixing system upgrade with implementation of the booster technology (see below) will finally lead to a projected 4-fold increased methane production at the current PNCC WWTP digester facility at a fraction of the costs for the alternative construction of new digester tanks (see 2.4). A recent survey of available industrial waste materials (whey, piggery slurry) established a matching waste potential within less than 20 km radius from the WWTP that is suitable for co-digestion with the primary sludge and is sufficient to produce in total approx. 120 $m^3$ methane/hour (data not shown). Stage 1 has now been implemented with improved biogas recirculation mixing in PNCC digester tank 1 and improved hydraulic mixing in PNCC digester tank 2.

**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. It is Waste Solution's experience that the additional 1.5—2 fold increase in the digester biogas production can be achieved by a combination of (i) preferential digestion of trade and industrial waste materials with high fat contents (grease trap waste, floatation foams etc.) and (ii), implementation of recuperative digester sludge thickening and return of thickened, active anaerobic digester sludge into the digester which increases the methane yield and volatile solids destruction (booster technology; Thiele, 2000).

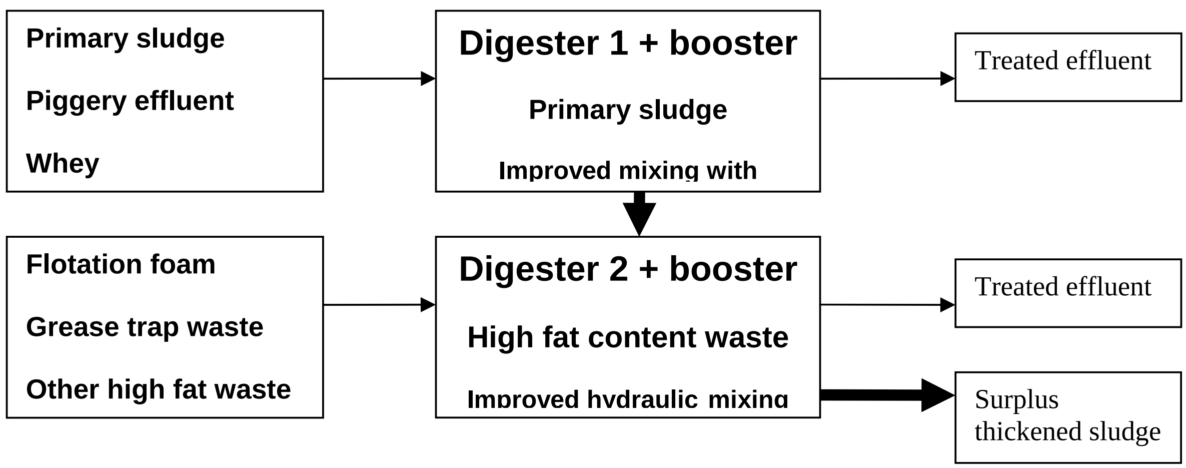
Booster technology is based on digester effluent treatment in a subsequent thickening step (decanter centrifuge, screw thickener, table thickener, belt thickener etc.). This allows to return a pre-thickened very active anaerobic sludge into the digester. With a higher sludge capture, the digester can be safely operated at shorter hydraulic residence times (less than 10 days) because the sludge washout is counteracted by the booster effect. In addition, the digester discharges a higher quality, filtered effluent with lower solids content. And by "boosting" the digester activity, an adjustable portion of the pre-thickened digester sludge can also be sent to dewatering when it is convenient for the digester facility operation. Booster technology provides thus a very flexible solids management system for anaerobic digesters.

Booster technology allows also to effectively digest feedstocks with high contents of fat, oil and grease. Typically over 90 % fat digestion efficiency is achieved (J H Thiele, unpublished). 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 fat digesters. 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 PNCC WWTP digester facility feedstock showed that the average digester feedstock composition needed for a baseline production of 180 $m^3$ methane/hour has a solids content of 6.2 % and a fat content of at least 31 % fat, oil and grease in the feed material volatile solids (data not shown). It is planned to install booster technology in both PNCC digester tanks as soon as high fat content trade waste materials are available for biogas production.

**Digester facility operation risk minimization:** A key consideration for the implementation of co-digestion schemes in municipal digesters is the requirement of zero impact of co-digestion on the WWTP performance. All waste materials needs thus to be liquids/slurries and free of materials that can interfere with the proper functioning of the digester process. Figure 6 below summarizes the recommended arrangement of process steps and best practices that are required to give the upgraded PNCC WWTP an increased baseline biogas productivity of 180 $m^3$ methane/hour without impact on the primary sludge digestion. Digester 1 is dedicated to primary sludge stabilization. Fitted with improved gas recirculation mixing and a booster step it provides more operational security for primary sludge digestion in one tank than in the current partly mixed two sludge digester tanks. In case of an digestion inhibition event in digester 1 due to unknown primary sludge components, the sequential arrangement of digester 1 and 2 plus the installation of improved mixing and booster technology in both digester tanks provides a 3-4 fold increased treatment capacity security and thus reduced operation risk when compared to the current status quo with two partly mixed tanks. Thus the co-digestion scheme at the PNCC WWTP prioritizes primary sludge digestion over methane production. Waste Solutions recommend this co-digestion process operation strategy as a default choice. It is recommended and feasible because natural gas is permanently provided as generator back-up fuel guaranteeing the electricity production and digester heating even if the acceptance and co-digestion of other waste must be temporarily stopped.

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




**Implementation of specific design features for digestion of high fat content industrial waste:** Operational issues such as foam formation are expected in biogas recirculation mixed high fat content sludge digesters. The projected final biogas production for the PNCC digester facility is on average 2.4 $V_{biogas} .V_{digester}^{-1} . day^{-1}$. This is practically a fourfold increase over the current average biogas production at the PNCC WWTP (0.6 $V_{biogas} .V_{digester}^{-1} . day^{-1}$). The conceptual process schematic given in Figure 6 shows that digester 1 handles the full primary sludge treatment duty of the WWTP and no high fat content waste (see section 2.3 for results) whereas digester 2 is specially equipped for digestion of feed materials with high fat contents by minimizing biogas recirculation mixing. The mixing system upgrade in digester 2 with hydraulic mixing only has thus the purpose to minimize foam formation risks.

Another key feature in Figure 6 is that surplus thickened anaerobic sludge from digester 1 is continuously transferred into digester 2 to provide additional fat digestion capacity and active seed culture. This is an effective risk minimization strategy for digester 2 and provides an additional source of active anaerobic sludge in case of digester 2 inhibition from unintentional overload with fat materials (Broughton et al, 1998). Finally, only surplus thickened sludge from digester 2 is “wasted” to sludge dewatering - therefore this process makes maximum use of the methane bacteria recycled through two booster systems and the sequential process arrangement of the two digester tanks. The typical volatile solids (VS) reduction efficiency in this configuration is expected to be overall around 75-80 % and the VS reduction efficiency for fat, whey and floatation foams is expected to be > 90 %.

## 2.2 PRACTICAL DIGESTER MIXING SYSTEM UPGRADE OPTIONS

### 2.2.1 LOW COST MIXING UPGRADE WITH BIOGAS RECIRCULATION

Based on a concept design and detailed design provided by Waste Solutions, PNCC installed in December 2008 a system of 20 peripheral Pearth biogas lances in digester 1 that were inserted through the gap between the floating roof and the digester wall. The Pearth lances are organised into 5 sets of 4 lances on individual manifolds and each manifold is actuated by a manual valve. This was the quickest and least expensive option to provide additional digester mixing. The system was designed to provide additional biogas mixing for 8 hours every day to break up stagnant digester liquor zones at the tank periphery (dead zones) and to avoid flow short circuiting for the existing hydraulic mixing. This mixing system upgrade operates satisfactorily since April 2009 (see 2.3) virtually doubling the effective digester working volume, reducing the acceptable hydraulic residence time to less than 15 days and allowing treatment of the full daily primary sludge load with a single digester tank. Only two out of the five Pearth lance sets in digester 1 are operating at any point in time to minimise foam formation. The construction and implementation costs for this option were less than 40,000 $. Added operating costs are insignificant because the peripheral Pearth lance sets are operated by the existing biogas blower. The cost benefit ratios are summarised in section 2.4.

### 2.2.2 LOW COST HYDRAULIC DIGESTER MIXING UPGRADE OPTION

Based on a concept design and detailed design provided by Waste Solutions, PNCC installed in July/August 2009 a new hydraulic digester mixing system in digester 2. The design replicates parts of the successful digester mixing system upgrade that was previously designed and implemented by Waste Solutions for the Tauranga City Council at the Chapel Street Digesters. The hydraulic mixing system 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.

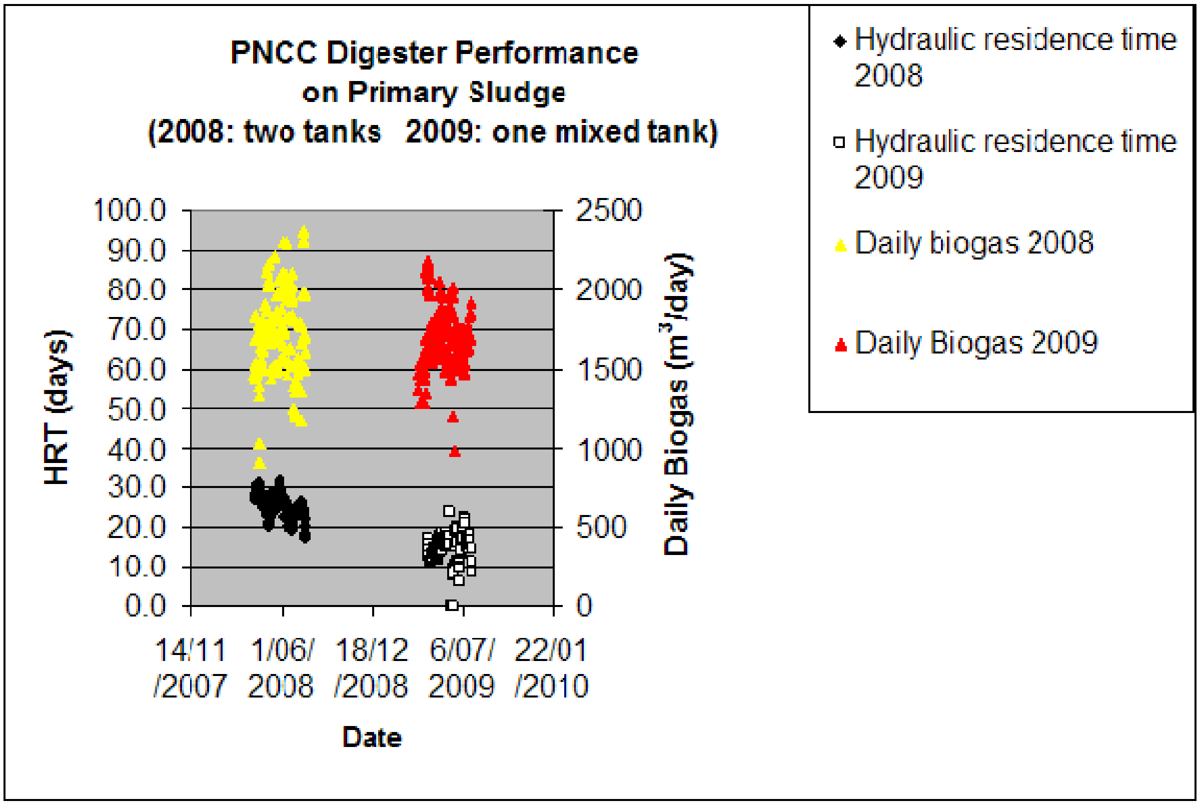
## 2.3 PRACTICAL RESULTS

### 2.3.1 PRIMARY SLUDGE DIGESTION AT 15 DAYS HYDRAULIC RESIDENCE TIME

The Lithium tracer test presented in Figure 5 demonstrated that dead zones and poor mixing in the PNCC digesters caused an effective combined HRT of 13.2 days under normal operation conditions despite a calculated combined HRT of 20-30 days. Both digesters were stable and achieved good primary sludge degradation under these conditions. Therefore it was concluded that stable PNCC primary sludge digestion should be feasible in a single well mixed digester tank when operated at 15 days HRT. To initiate the digester cleanout and mixing system upgrade for the fatty waste digester train 2 (see Figure 6), digester 2 was taken out of commission in April 2009 and the full PNCC primary sludge load digested by digester 1 with an upgraded biogas recirculation mixing system (see 2.2.1). 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 7

The daily biogas production of 1677 +/- 197 $m^3$/day recovered in 2009 from a single digester tank treating the whole primary sludge daily load was virtually indistinguishable from the biogas production results in the same months for the previous year with two tanks in operation (1712 +/- 276 $m^3$/day). The nominal digester HRT in 2008 was 25.3 +/- 3.2 days for two digester tanks with an average daily primary sludge inflow of 109 +/- 27 $m^3$ per day whereas the nominal digester HRT in 2009 was only 15.1 +/- 3.8 days with an average daily inflow of 91 +/- 24 $m^3$ per day. PNCC concluded therefore that the low cost mixing system upgrade in digester 1 (see 2.2.1) was effective and had increased the treatment capacity of the digester plant by approx. 100 %. The mixing system upgrade in digester 1 made digester 2 available for additional biogas production duties via co-digestion of additional industrial waste (see Figure 6).

**Figure 7:** Comparison of PNCC WWTP primary sludge daily biogas production from two inefficiently mixed digester tanks (2008, yellow symbols) with the biogas production from one well mixed digester tank (2009,red symbols).




### 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 the upgrade to a co-digestion facility can be implemented without significant interruption of normal operations. 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 for about one week. After that, digester 1 was suitably equipped to effectively accept the full daily primary sludge load (see Figure 7). 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 7). Once the hydraulic mixing system in digester 2 is fully commissioned (expected in November 2009), stage 1 of the upgrade has been implemented without interruption of the WWTP operation.

For stage 2, PNCC plans for 2010 the implementation of recuperative sludge thickening in digester 2 followed by implementation of a separate thickening module in digester 1. Waste reception facilities for liquid waste are already in existence and new facilities will be added as soon as needed. Thus the gradual retrofit of the digester plant from a municipal biosolids sludge digester into a modern industrial waste co-digestion facility can be completed without interruption of the WWTP operation.

## 2.4 COST/BENEFIT ANALYSIS

The actual operation performance data presented above (Figure 7) have demonstrated that stage 1 of the digester facility upgrade has created at least a 100 % increased treatment capacity at the PNCC sludge digesters. With capital costs for the stage 1 upgrade of less than 260,000 $ (digester 1 and digester 2), this process oriented digester facility upgrade has allowed to infinitely defer the construction of one new 1,350 $m^3$ digester tank with gas handling 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 260,000 $ has substituted a capital asset purchase in the order of 1.5 million $. This result demonstrates the cost effectiveness of the strategy and design that Waste Solutions has developed for the PNCC digester mixing upgrade in stage 1. In addition, the upgrade of digester 2 with modern hydraulic mixing enables PNCC to receive and digest high fat content waste and to collect additional gate fee income for the treatment of additional industrial and trade waste.

Similar economic considerations apply to the planned upgrade in stage 2 with installation of the booster technology on both digesters in 2010. At expected capital costs of about 500,000 $ ( +20 %, - 10 %) for two booster modules installed, the daily biogas production capacity is expected to increase from 4,500 $m^3.day^{-1}$ to about 6,500 $m^3.day^{-1}$ saving the purchase and installation of another 1,350 $m^3$ digester tank and avoiding additional capital expenditure in the order of 1.5 million $.

Thus in combination, the stage 1 and stage 2 upgrades at the PNCC digester plant are scheduled to create capital assets equivalent to a value of 3 million $ at actual costs of about 750,000 $. The municipal digester plant upgrade strategy to a modern co-digestion facility proposed, designed and tested by Waste Solutions 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 1 summarises the expected costs and benefits for the upgrade of the PNCC sludge digesters from municipal digesters into a commercial co-digestion facility for concentrated liquid waste from trades, agro-industries and municipal sources. The total upgrades is expected to achieve a simply payback period of less than 2 years for an initial capital outlay of approximately 750,000 $NZ.

**Table 1:** Preliminary cost : benefit analysis for the expected performance of the PNCC digester upgrade to a co-digestion facility. 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 actually collected gate fee and the additional operating costs for waste collection, transport and reception at the co-digestion facility.

| Upgrade stage (simple payback period) | Digester tank | Capital cost estimates (NZ$) | Additional Biogas (kwh/day) | Additional biogas value (NZ$/annum) | Waste processed (t/annum) | Gate fee (10 $/t) (NZ$/annum) |
|---|---|---|---|---|---|---|
| **Stage 1** | **Dig 1** | **40,000** | **0** | **0** | **0** | **0** |
| | **Dig 2** | **220,000** | **18,000** | **170,000** | **22,000** | **220,000** |
| **Total stage 1: (8 months)** | | **260,000** | **18,000** | **170,000** | **22,000** | **220,000** |
| **Stage 2** | **Dig 1** | **250,000** | **0** | **0** | **0** | **0** |
| | **Dig 2** | **250,000** | **14,400** | **136,600** | **11,000** | **110,000** |
| **Total stage 2: (24 months)** | | **500,000** | **14,000** | **136,600** | **11,000** | **110,000** |
| **Total upgrade: (15 months)** | | **760,000** | **32,000** | **306,600** | **33,000** | **330,000** |

# 3 CONCLUSIONS

In conclusion, this paper has demonstrated that a thorough digester process analysis prior to a digester system upgrade can save significant capital costs and can provide investment opportunities with simple payback periods below 2 years. The importance of the last point should not be underestimated. In times of constrained financial resources and limited liquidity, capital works that can be executed with full technical performance at ¼ of the alternative costs are likely to attract venture capital if investment payback periods of less than 2 years can be realized. That is an important element for a countrywide introduction of industrial waste co-digestion schemes in other centers in New Zealand.

The digester upgrade technologies employed have shown a demonstrated performance at PNCC and other sites and thus do not constitute a technical risk. The waste materials for the co-digestion facility are carefully selected to minimize/eliminate digester process risks and thus ensure adequate biogas production for the production of renewable electricity.

PNCC and Waste Solutions have successfully worked together to pioneer and realize this opportunity which reduces the waste management costs for industry and rate payers, diverts highly putrescible waste from landfills and generates green electricity at competitive costs. The potential carbon credits associated with the industrial waste co-digestion facility have not yet been fully assessed but may add additional revenue to the venture.

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