CAPACITY UPGRADE OF MUNICIPAL SLUDGE DIGESTERS – THE HAMILTON EXPERIENCE

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ABSTRACT

The Hamilton City Council (HCC) initiated in 2012 the upgrade of its Pukete treatment plant digesters for treatment of increased biosolids loads (> 60 % load increase expected in next decade). Capacity upgrade was achieved in existing digesters and without plant operation interruption. Improved mixing in the methane digesters and recuperative thickening increased the digester liquor solids content from 1.5 % TS to 3 % TS, uncoupled hydraulic and solids residence time and doubled solids residence time and treatment capacity. High digester process stability was observed indicated by low volatile fatty acids (VFA; typically less than 30 mg VFA/L), high pH (pH > 7), high alkalinity (> 2500 mg/L) and high solids content in the mixed liquor (2.9 % – 3.2 % TS). The constructed volume of the upgraded digesters was fully available for biosolids treatment (Lithium tracer test). The digester process robustness was significantly improved. At completion, the digesters could treat 200 % of the current sludge flow and 180 % of the current biosolids load at a fraction of the CAPEX costs that would have been incurred for construction of equivalent new sludge digesters. HCC was able to defer capital costs for construction of new digester tanks until 2020.

KEYWORDS

Municipal, thickening, sludge, methane, digestion, treatment, CAPEX

1 INTRODUCTION

Growth in our primary processing industries (dairy and food processing) and a growing population base have produced a significant resource of municipal biosolids and trade waste which could be used to supply the power demand for our municipal wastewater treatment infrastructure (pumping, aeration) by anaerobic digestion (Thiele, 2012). A cost effective and smart way to create the additional digester capacity in existing sludge digesters is the retrofit/upgrade with recuperative sludge thickening ("digester booster technology"; Thiele, 2000; Thiele & Hearn, 2004).

The "booster technology" uncouples hydraulic and solids residence time in anaerobic digesters, returns the sludge solids back into the anaerobic digesters and achieves solids residence times in the order of 200 % of the respective hydraulic residence times. In addition, the anaerobic sludge bacteria in the digester are 2-3 fold concentrated. Anaerobic digesters with booster technology are thus designed to increase their hydraulic throughput, increase their daily biogas production capacity and minimize the washout of the slow growing anaerobic bacteria from the digester despite an increased hydraulic throughput. The net result of this are more robust digesters with increased sludge concentration, higher capacity for sludge digestion, higher daily biogas production capacity, higher hydraulic treatment capacity and an improved solids residence time (SRT) for the municipal biosolids to be treated.

Full-scale operation of sludge digesters with recuperative thickening was trialled at the Spokane WWTP, Washington US. The results presented show that with essentially no added capital cost (use of existing DAF), the plant operation achieved an increase in volatile solids reduction efficiency from 50 to 64%, 15% lower polymer consumption and 22% lower digested biosolids production (Reynolds, et al., 2001).

This approach was implemented for the first time in New Zealand at the Palmerston North City Council (PNCC) Totara Road plant (Thiele, 2010). The PNCC digester capacity upgrade using drum thickener technology increased the digester solids throughput capacity (kg TS/day) to 200 - 300 % of the original design capacity at construction costs of less than 500 $ /m^3 additional digester working volume equivalent created (Thiele & Burt, 2014). Compared with $1,000 – $1,500 per m^3 digester for the construction of equivalent new digester volume, the digester capacity upgrade approach with recuperative thickening is thus now a proven alternative to construction of new digester tanks.

The Hamilton City Council (HCC) municipal biosolids digesters at the Pukete wastewater plant treat their biosolids load in a two stage mesophilic sludge digester system comprised of an acid stage with 1-2 days nominal HRT followed by a methane stage with 12 days nominal HRT. The methane stage is comprised of two parallel digester tanks with about 2,200 m^3 working volume each. HCC expects its biosolids production (primary sludge and thickened WAS) to increase by more than 60 % over the next decade. Initial mixing and HRT tests by Spiire in 2011 established that the methane stage digester performance was overall biosolids digestion rate limiting at the Pukete plant. The tests showed further that the mesophilic sludge digesters had reached the limits of their biosolids treatment capacity due to inefficient digester mixing in the methane stage. Downer and Spiire proposed to HCC to implement a methane stage digester treatment capacity upgrade following the general approach of the successful previous digester capacity upgrade completed, by Spiire, at the PNCC digesters.

HCC engaged Downer New Zealand in 2012 as head contractor for the design and build of the capacity upgrade of the two methane stage digesters. Downer engaged Spiire to design the upgrade works and provide commissioning support for the two methane stage digester capacity upgrade at the HCC Pukete wastewater treatment plant. As in the PNCC digester upgrade, the final design focussed on (a), completion of all construction works on the operating plant without interruption of sludge treatment; (b), automation of all critical operation steps; (c), addition of a hydraulic mixing system to minimise “digester dead volume”; and (d), installation of an automated recuperative sludge thickener system to effectively double the hydraulic treatment capacity and solids residence time in the digesters.

Construction of the digester capacity upgrade was programmed in 3 separate stages with (i), the preparation of the digester plant for isolation of methane stage digester 2 (MD2, completed in June 2013), (ii) the capacity upgrade of MD2 (completed in October 2013) and (iii), the capacity upgrade of methane stage digester 1 (MD1) (scheduled to be completed in August 2014).

This paper reports the process design philosophy, the achieved methane digester performance and treatment capacity increase after the completed upgrade and the operator experience with the methane digester after the capacity upgrade.

2 EARLY CONTRACTOR INVOLVEMENT

HCC approached the market for potential options to address the capacity limitations of the existing methane digesters. HCC was seeking an innovative solution which would allow to postpone the requirement for the construction of a third digester. Downer and Spiire presented HCC with the recommendation to adopt a recuperative sludge thickening process similar to the PNCC Wastewater Treatment Plant digester upgrade.

The Downer/Spiire team was initially engaged by HCC to investigate the suitability of the Hamilton installation for the proposed upgrade. The scope of this early involvement consisted of extensive analysis of the sludge chemistry, a review of the historic digester performance data as well as completing Lithium tracer tests to ascertain the effectiveness of the gas mixing system installed within the existing digester tanks.

Following this work, the Downer/Spiire team worked closely with HCC to develop a preliminary design for the proposed upgrade which met the requirements of Council. Based on this design and a clear set of KPIs, Downer developed a Guaranteed Maximum Price offer which was presented to HCC. A third party was engaged to review the pricing submitted by Downer to ensure Council were receiving value for money. The positive feedback from this review allowed HCC to enter into a design and build contract with Downer.

3 GENERAL DESCRIPTION OF UPGRADE

The final solution consisted of the following elements:

1. Installation of a drum thickener unit for recuperative digester sludge thickening with a processing capacity of about 1,000 kg TS /hour of anaerobic digester sludge.

2. Installation of a dedicated polyelectrolyte make up unit for the thickener plant.

3. Sludge pumping systems for the thickener plant to and from the digesters.

4. Construction of a new plant building to house the thickener plant and associated electrical systems and the process control and Supervisory Control and Data Acquisition (SCADA) systems for the thickener plant.

5. Installation of 6 shunt pumps (3 per digester) to return floatable material to the base of the tank, preventing the formation of a scum layer and maximizing the working volume of the digester.

6. Installation of ring main hydraulic mixing systems to each digester to provide uniform digester mixing

7. Replacement of existing heat exchangers for both methane stage digesters

Figure 1 presents on overview over the upgraded works with the key features indicated.

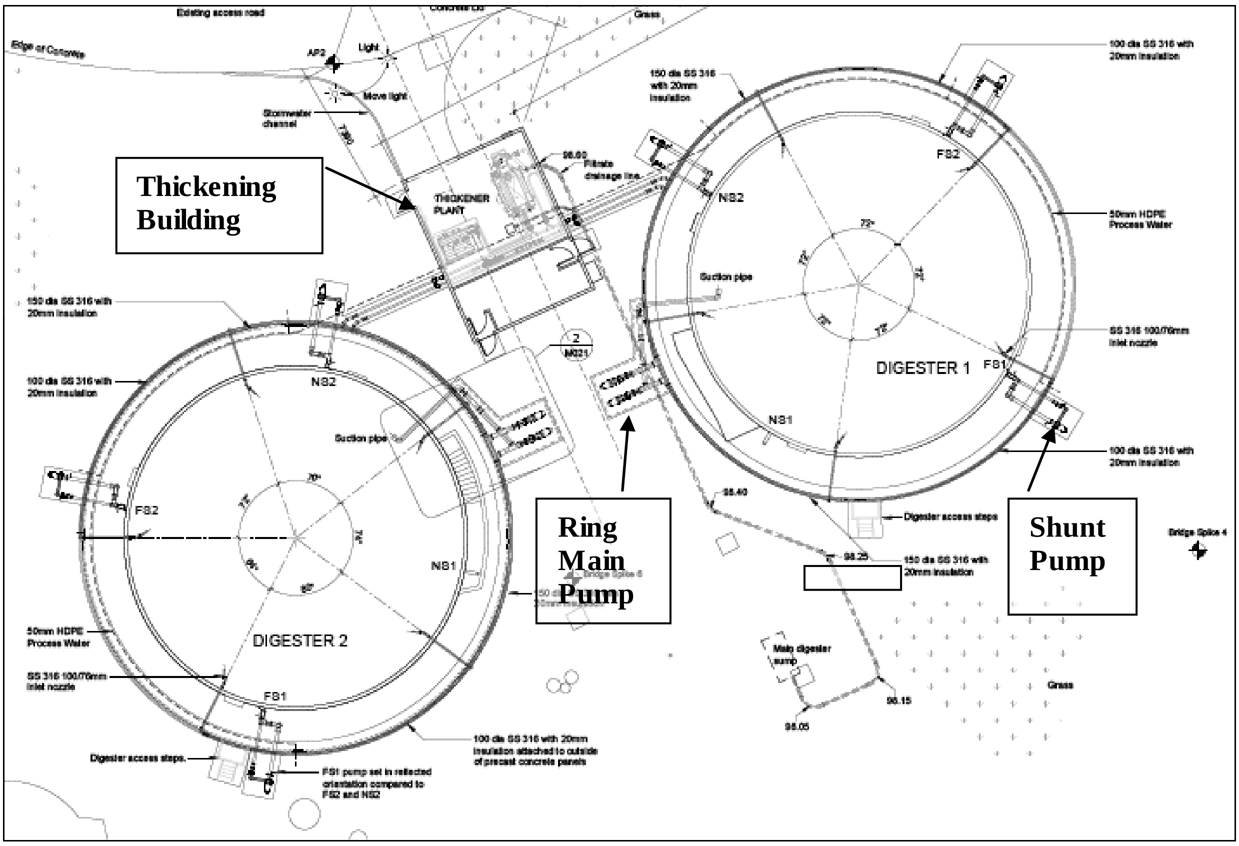

Figure 1: Drawing reflecting the upgraded configuration of the HCC Pukete WWTP Methane Digesters,

In addition to the construction works described above the upgrade also included to drain down and empty both digesters and the full commissioning (mechanical, electrical and process) of the upgrade.

4 CAPACITY UPGRADE OF METHANE DIGESTER 2 (MD2)

This paper discusses in detail the results associated with the fully upgraded methane digester MD2 only, because at time of writing the methane stage digester MD1 had only been operated in a partially upgraded condition. It is anticipated that the results obtained with MD2 are representative of the anticipated performance of the fully upgraded MD1 as both digesters were upgraded to an identical final digester process configuration.

4.1 METHODS

4.1.1 LABORATORY ANALYSES

All chemical laboratory analysis data presented here were obtained with standard methods (APHA, American Public Health Association) routinely practiced by the HCC Pukete WWTP site laboratory (TS, VS, pH, TSS, VSS, alkalinity, VFA analysis by distillation and titration). TS % analysis of digester liquor samples presented in Figures 6 and 7 were obtained with an automatic moisture analyzer (Sartorius, model MA35). The specific rate (activity) for methane production by the anaerobic sludge in the methane stage digesters (kg methane COD formed/kg sludge VSS/day) was determined at 35 ^{o}C in sludge activity tests as described elsewhere (Thiele & Hofmann, 2012) with samples taken from the digester MD1.

4.1.2 DIGESTER OPERATION DATA FROM PUKETE WWTP SCADA SYSTEM

Data about daily biogas production from MD1 and MD2, daily volumes of acid stage effluent loaded to MD1 and MD2 and digester operating temperatures were obtained from the daily summary data for both digesters retrieved from the Pukete WWTP SCADA system. Daily polymer consumption figures (ZETAG 8180, cationic polymer) used for the polymer dosing plant in the recuperative sludge thickener and the dewatering plant were obtained from operator logs. The activity of methane production by the anaerobic sludge in the methane stage digesters (kg methane COD formed/kg sludge VSS/day) was determined by calculation from the daily methane production and the sludge volatile suspended solids (VSS) inventory in each digester tank. The anaerobic sludge inventory (kg VSS/digester tank) for each digester tank was calculated from the effective working volume of the digester tank on the day (logged on SCADA system) and the laboratory based chemical analysis of TS, VS, TSS and VSS of respective digester sludge samples taken from each methane stage digester tank.

4.2 DIGESTER PROCESS PERFORMANCE RESULTS AND DISCUSSION

4.2.1 OVERVIEW OF IMPLEMENTED DIGESTER PROCESS CONFIGURATION

Figure 2 below presents the process arrangement selected for the capacity upgrade of the Pukete methane stage digesters. The acid stage digesters and sludge holding tank (SHT) upstream of the acid stage digesters remained unaffected by the upgrade and are therefore not shown. The process configuration in Figure 2 was chosen by HCC to allow discharge of the thickener filtrate by gravity flow into the existing digester supernatant sump and to convey the excess methane digester sludge either by pumping (bottom withdrawal off take point) or overflow (fill and spill) into the digester supernatant sump. All sludge materials were then pumped from the supernatant sump to the dewatering day tank and processed in the existing dewatering centrifuge plant. The installed drum thickener in the thickener plant (Teknofanghi screw drain, double drum arrangement, see Photograph 1, section 5) was programmed into four user selectable operation modes:

- Mode A: methane digester 1 content (blue arrow) returned thickened into MD1 (red arrow)
- Mode B: methane digester 2 content (blue arrow) returned thickened into MD2 (red arrow)
- Mode C: methane digester 1 content (blue arrow) returned thickened into MD2 (red arrow)
- Mode D: methane digester 2 content (blue arrow) returned thickened into MD1 (red arrow)

The thickened sludge from the recuperative thickening was recovered with a solids content of 6.5 – 7.5 % TS and with a solids capture efficiency in the vicinity of 90 % (see also Figure 7 below). The thickener filtrate was recovered with a solids content of less than 0.3 % TS and had already been corrected for any dilution by potable water needed for drum thickener fabric cleaning (see section 5.2.4).

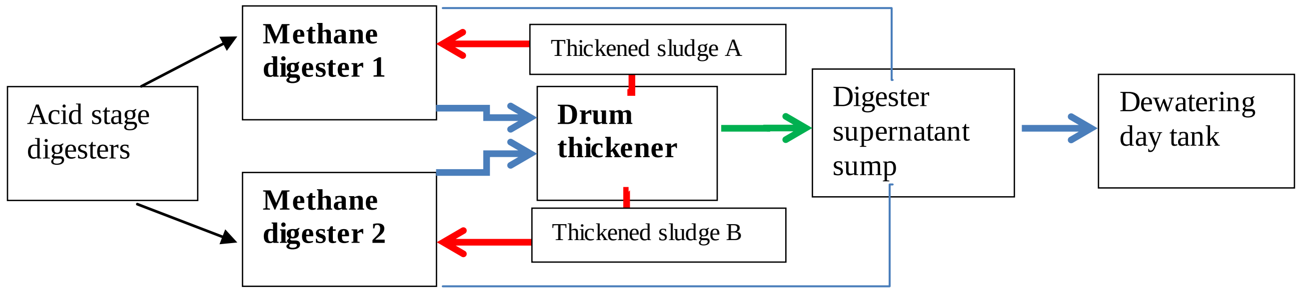

*Figure 2: Process flow for the biosolids treatment capacity upgrade of the Pukete digester plant. The thickened sludge return is indicated by the **red arrow**, the filtrate discharge to the supernatant sump by the **green arrow** and the digester liquor flow by the blue lines/arrows.*

Typically, the drum thickener was programmed to process the daily volume of acid stage effluent that enters each digester tank and to return approximately 30 – 40 % of that processed volume in the form of thickened sludge back into the digester tank. Surplus volume from the digester tank was discharged by overflow into the digester supernatant sump.

The inclusion of recuperative thickening was a critical process design element for the digester upgrade because the brief specified the upgrade to be done on the operating plant without interruption of the sludge treatment operation. The drum thickener could be connected to the digesters via existing wall penetrations and valves while the plant kept operating as normal. "Thickening up" of one digester tank at the time from 1.5 % TS to 3 % TS (see also Figure 2, 3 and 4 below) created additional treatment capacity in the digester that allowed to" take down" the other digester tank for cleanout and installation of the improved digester mixing systems (see below).

Poor mixing in biogas recirculation mixed methane digesters found at the HCC Pukete plant was consistent with the previous findings at the PNCC digesters (Thiele, 2010) which demonstrated that up to 50 % of the digester volume in biogas recirculation mixed sludge digesters can be stagnant liquid that does not effectively contribute to the hydraulic and solids treatment capacity in sludge digesters.

Table 1: Summary of Lithium tracer distribution based (for methodology please see: Thiele, 2010) Mixing and HRT test results and expected treatment capacity improvement for the Pukete methane digesters. The nominal working volume of each digester tank used for the calculations was 2150 m^3.

	Nominal HRT at time of test	Actual HRT at time of test as determined by Li tracer washout kinetics	Relative effective digester working volume improvement through better mixing and removal of stagnant digester liquor (% of nominal working volume)
Pukete, MD1 October 2011	11 days	6.7 days	61 %
Pukete, MD2 November 2011	11.2 days	8.6 days	30 %

The improvement of the digester mixing efficiency was the 2nd key design element of this digester upgrade. Two Lithium tracer based mixing and HRT tests were carried out with the same test methodology as previously used for the PNCC upgrade (Thiele, 2010). The mixing and HRT test results summary are presented in Table 1. About 40 % of the nominal digester working volume in MD1 was identified as stagnant liquid in the Li tracer washout phase resulting in an effective hydraulic residence time (HRT) of 6.7 days. However, the tracer rapidly distributed into 100 % of the nominal digester working volume demonstrating minimal digester sediment build-up in MD1 (data not shown). The results suggested that flow short circuiting in MD1 prevented effective contact between fresh digester feed and the resident active anaerobic sludge in the digester. This flow short circuiting reduced the HRT and SRT in methane digester MD1 to 6.7 days.

The test data for digester MD2 (Table 1) showed a slightly different picture. About 23 % of the nominal digester volume was found to be filled with firm sediment build-up because the tracer chemicals could not distribute into that volume. Whereas the balance of the digester MD2 working volume was reasonably well mixed. Sediment build-up in anaerobic digesters is often an indication of inefficient local mixing.

Table 2: Pukete digester upgrade design elements and the expected treatment capacity improvements.

Digester Upgrade design elements	**Technology used**	**Mixing rate (m^3/h)**	**Expected treatment capacity gain** (% of capacity prior to upgrade)
(A) Improved vertical distribution of floating foam to the digester base	**Shunt Pump Mixing System** (3 shunt pumps/digester tank)	300	30 %
(B) Improved transport of thickener return sludge and stagnant digester liquor to the digester base	**Ring Main Mixing System** (2 pumps/digester tank, duty & assist)	300 (600)	30 %
(C) Thickening of digester liquor from 1.5 % TS to 3 % TS	**Recuperative Thickening System**	15	100 %

Table 2 above lists the relative contribution of the digester upgrade elements used to the overall solids treatment capacity gain in the upgrade. Please note that while the mixing effect of the recuperative thickening system is minimal, its contribution to the treatment capacity improvement is very significant because the solids concentration increase through recuperative thickening doubles the capacity gains made by the mixing system improvements. Please note that the capacity gains from shunt pump mixing system and ring main mixing system are additive as they address different sections of the digester tank.

4.2.2 DIGESTER SYSTEM PERFORMANCE DURING THE CAPACITY UPGRADE

A critical step in the digester upgrade works was the confirmation that sludge recovery by dosing of cationic polymers with the drum thickener had no detrimental effects on the health and activity of the key anaerobic bacteria in the digester sludge. The specific activities of these bacteria were determined under controlled laboratory conditions (Thiele & Hofmann, 2012) in sludge samples from the Pukete digesters. In addition, specific activities of the sludge bacteria were also estimated from daily biogas production data retrieved from the SCADA system at the Pukete plant (Table 3).

The results shown in Table 3 demonstrate that the daily addition of polymer (about 10 kg polymer/ t sludge dry solids thickener input) and the recuperative thickening process had no detrimental effect on the anaerobic sludge despite the increased risk for occasional exposure to air (O_2) in the recuperative thickening process. Table 3 shows further that the specific activity and sludge health was actually improved (about 100 % improved activity) on full scale with recuperative thickening for at least 6 months. Two series of tests from different digester plants, one done at the PNCC Totara Road digesters and one at the HCC Pukete plant presented a very similar sludge activity improvement. Unpublished data by Spiire show that the maximum specific sludge activity in the laboratory test in anaerobic sludge from industrial WWTP digester is typically 0.4 – 0.5 kg CH_4-COD/kg VSS/d. The specific sludge activity difference between municipal and industrial digesters is caused by contaminating residual non bacterial VSS materials in the anaerobic sludge from municipal digesters.

Table 3: *Controlled sludge activity tests (see Thiele & Hoffmann, 2012 for details on the methodology used) of the sludge in the digesters at HCC (Pukete). Values in* ***italics*** *font were independently determined on full scale from digester operation data without added test substrates. Specific COD removal activity data determined with anaerobic sludge from the PNCC digesters are presented for comparison.*

Parameter	2 tank operation without thickener prior to upgrade	1 tank operation with recuperative thickener, 6 months after upgrade	2 tank operation with recuperative thickener, 12 months after upgrade
Specific COD removal activity – HCC, Pukete digesters	0.05 kg CH4-COD/kg VSS/d	***0.11*** kg CH4-COD/kg VSS/d	***0.1*** kg CH4-COD/kg VSS/d
Specific COD removal activity-, PNCC, Totara Road digesters	0.07 kg CH_4-COD/kg VSS/d	0.14 kg CH_4-COD/kg VSS/d	0.15 kg CH_4-COD/kg VSS/d

In conjunction these data show that the chosen digester capacity upgrade practiced at the Pukete plant combined four different capacity enhancing factors:

(a) Recycle of floating sludge with the shunt pump system.

(b) Effective contacting of the digester feed material and the active anaerobic bacteria by combination of the shunt pump mixing system and the ring main mixing system.

(c) By using recuperative thickening, large increase of the effective concentration of the active anaerobic bacteria in the digester contents.

(d) Improvement of the specific COD removal activity of the anaerobic bacteria that were retained in the thickened digester contents.

Figure 3 below demonstrates the beneficial effects of the combination of these four factors in methane digester MD1 receiving 80 % of the full plant load in single tank digester operation. Maintaining digester MD1 with recuperative thickening at 3 % TS sustained a very high specific COD removal activity (above 0.1 kg methane COD formed/kg VSS/day) for a period of 5 months, stable digester pH (data not shown) and very low levels of VFA despite a very short hydraulic residence time in the digester (6.5 days HRT, determined by additional Li tracer distribution test, data not shown).

When the recuperative thickener was disconnected from MD1 end of November 2013 and the solids load to MD1 was re-adjusted to 50 % of the full plant load, two effects were observed: the enhanced anaerobic sludge washout decreased the TS % in the digester content and decreased the specific COD removal activity of the MD1 sludge at the same time. The underlying biological factors causing the beneficial effect of recuperative thickening on the specific COD removal activity of the anaerobic sludge are not well understood.

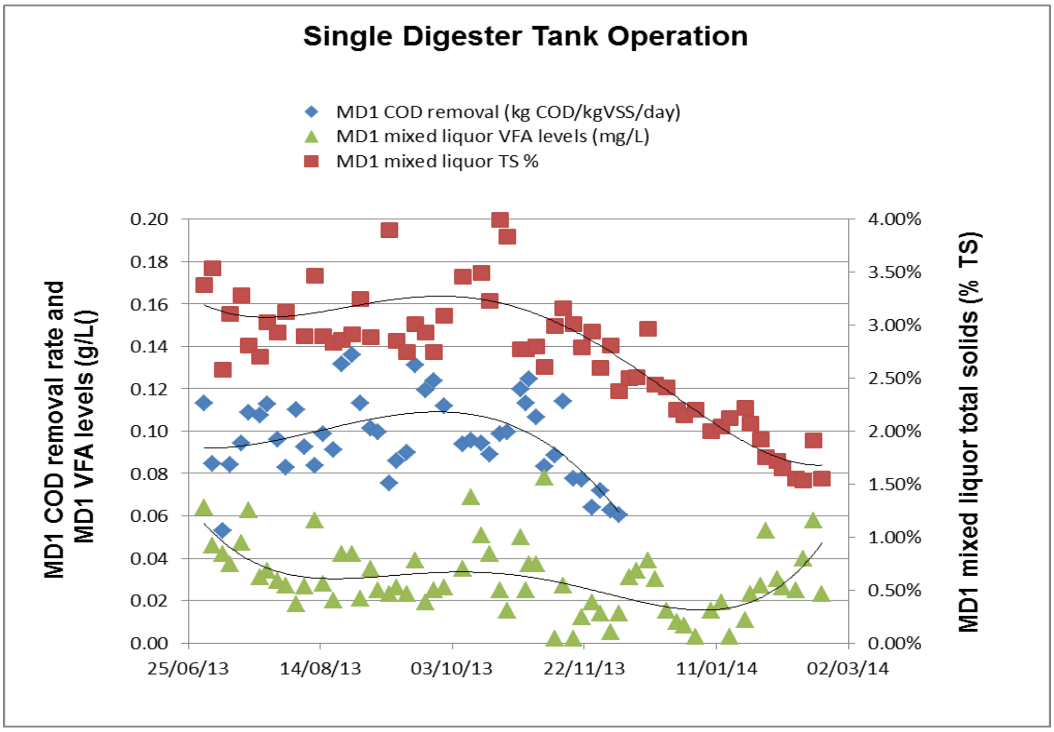

Figure 3: *Digester performance example for Pukete plant operation using a single methane digester tank (MD1) with shunt pump mixing and recuperative thickening while digester MD2 was upgraded.*

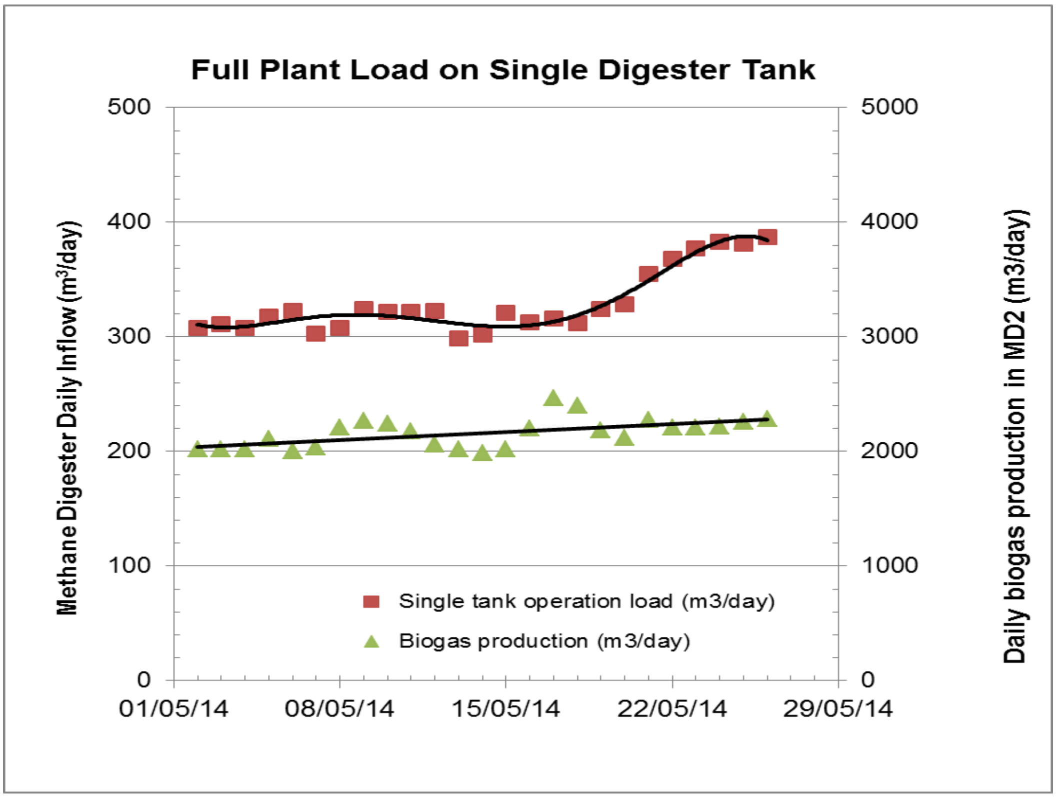

Figure 4: *Single tank operation performance of the fully upgraded methane digester tank MD2 receiving the full acid stage effluent load of the Pukete plant. Note that the stable daily biogas production despite an HRT of less than 5.6 days after 29/05/14.*

The beneficial effect of recuperative thickening on the digester stability in single digester tank operation was also seen in MD2 (Figure 4 above). The fully upgraded digester MD2 with operating shunt pumps and ring main mixing system received 380 – 400 m^3/day of acid stage effluent when digester MD1 was cleaned out in June/July 2014. A high rate of daily biogas production was sustained in MD2 at a stable digester pH (data not shown), VFA levels of less than 40 mg VFA/L (Figure 4) and a HRT of only 5.6 days. This demonstrates the importance of recuperative thickening for digester process stability at short hydraulic residence times.

Figure 5 shows that the active anaerobic sludge maintained with recuperative thickening at short HRT below 6 days is suitable as seed sludge for fast start-up of other sludge digesters. Transplanting MD1 sludge for 7 days into a water filled and heated MD2 tank in November 2013 directly after completion of the MD2 upgrade works immediately started biogas production at low VFA levels and a stable digester pH.

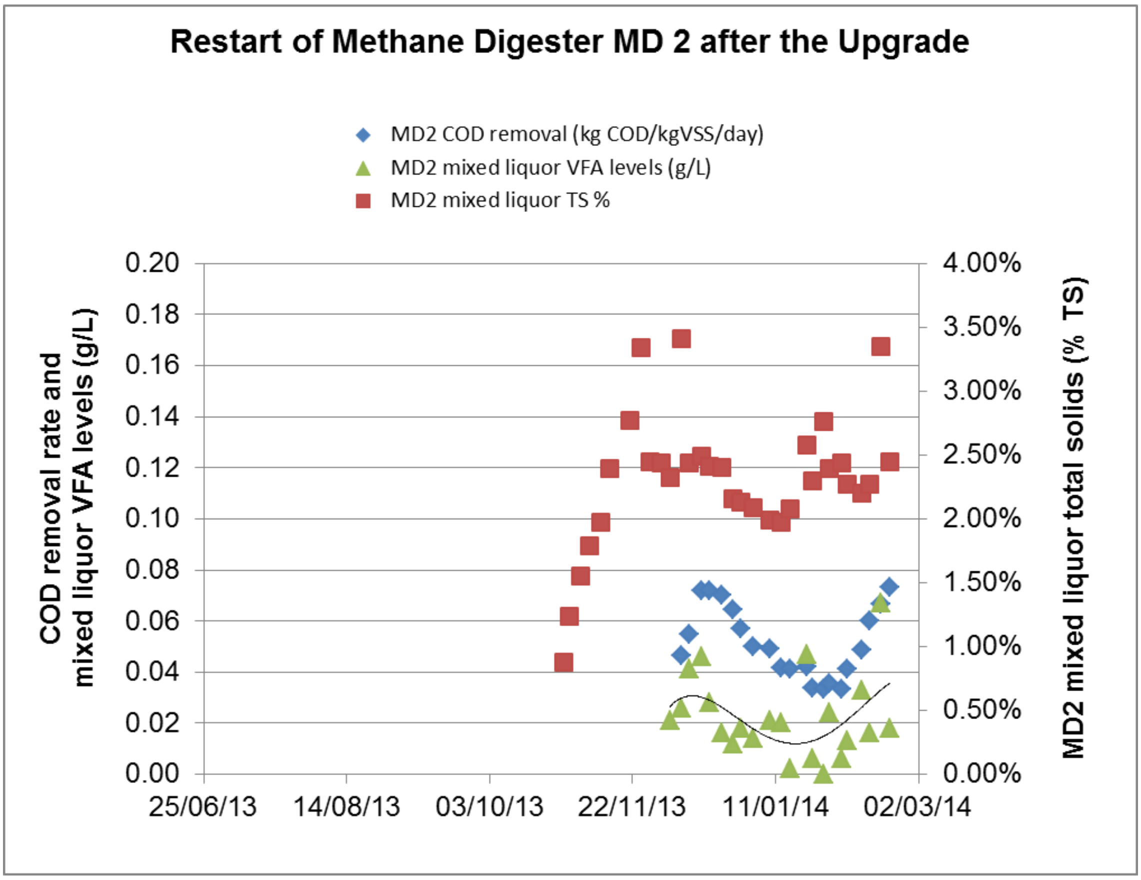

Figure 5: Example for restart of MD2 methane digester tank after completion of the upgrade works. Seed sludge was provided from the operating methane digester MD1 (see Figure 3.

4.2.3 DIGESTER MIXING SYSTEM PERFORMANCE AFTER COMPLETION OF THE UPGRADE

Improved digester mixing is critical for a successful methane digester capacity upgrade (see also table 2 above). MD2 was thus tested for the effectiveness of the upgraded digester mixing systems (Figure 6). For the test, the ring main mixing system was continuously operated at 300 – 330 m^3/hour and the 3 shunt pumps were continuously operated at 90 % of their full capacity. The mixing test was conducted over a TS % range from 2.2 % TS to 3 % TS in the digester liquor. Mixing efficiency was quantified by the difference between daily samples taken from (a), the digester base (bottom withdrawal), (b) the digester centre (well mixed by biogas recirculation and the ring main mixing system and (c), the top of the digester (typical location where scum and foam accumulate in poorly mixed digesters). Daily samples were taken from these points and immediately analyzed for their solids content and pH.

Figure 6 demonstrates that the mixing efficiency in the upgraded MD2 digester was high. Samples from all three sampling locations presented virtually identical TS contents within +/- 0.1 % TS variability. Bottom withdrawal samples with TS % contents typical for sediment sludge (6- 8 % TS) were not found (Figure 6).

These results demonstrate that the mixing system upgrade was adequate for the normal duty of the Pukete methane stage digesters when operated with recuperative thickening. As expected, the mixing efficiency will be slightly reduced when excessive amounts of “rag material” enter the digesters and increase the viscosity of the digester contents. Repeated sludge withdrawal from the digester base (bottom withdrawal) was an effective strategy to minimize the impacts of "rag materials" on the digester mixing efficiency (data not shown).

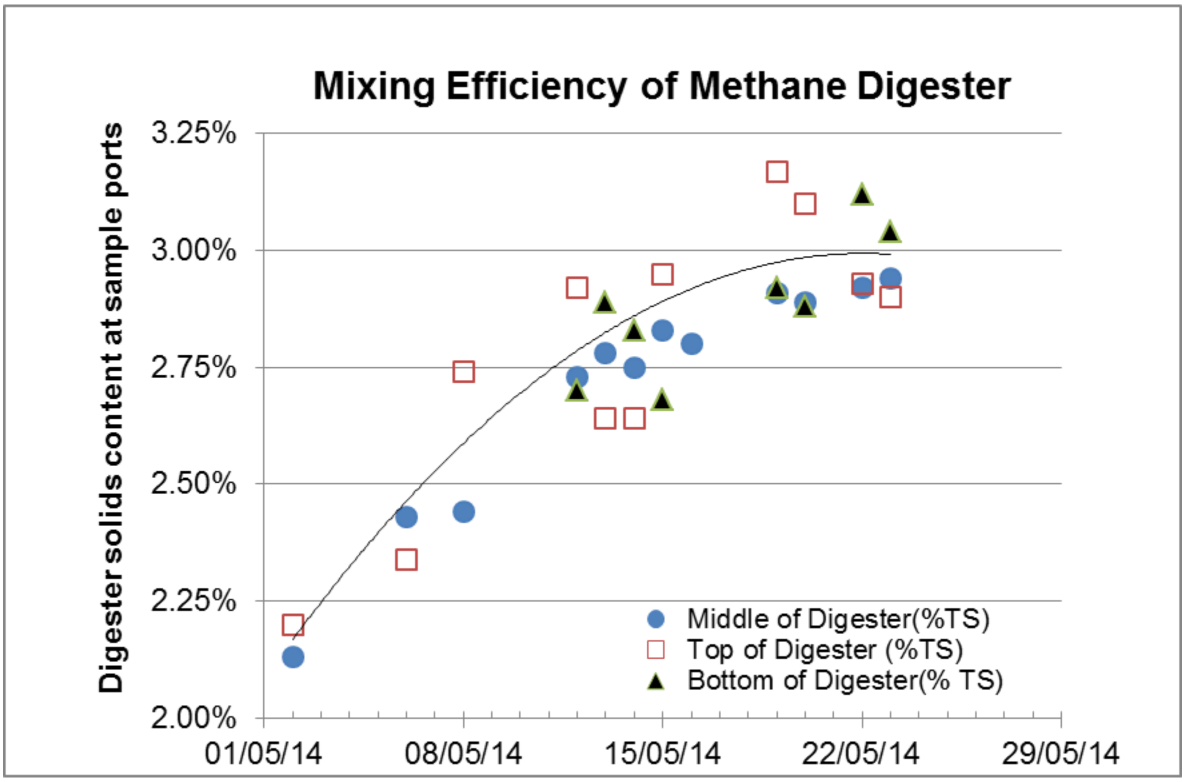

Figure 6: Mixing efficiency performance for methane digester tank MD2 with shunt pump mixing, ring main mixing and recuperative thickening after completion of the upgrade works. Data shown are in single tank operation mode for the full acid stage effluent load of the Pukete plant. The solids content (%TS) results in samples recovered from bottom, top and middle of the MD2 digester tank did not present increased variability when the digester solids content was increased from 2.2 % TS to 3 % TS.

4.2.4 THICKENER PERFORMANCE AFTER COMPLETION OF THE UPGRADE

The critical role of the recuperative thickening for the capacity increase of the sludge digesters made it necessary to assess the thickening effectiveness (Figure 7). In order to determine the effect of the solids content in the digester, the recuperative thickening assessment was conducted over a continuous TS % range from 2.6 % TS to 3 % TS. Thickening efficiency was quantified by the solids content (%TS) difference between samples from the thickener filtrate and from the thickened return sludge. Samples were regularly taken from these points during 2 digester hydraulic residence times and immediately analyzed for their total solids (% TS) content.

The thickened return sludge averaged about 7 % TS with +/- 0.7 % TS data variability. The thickener filtrate had a low solids content in the range of 0.1 – 0.3 % TS. The polymer dose added was 9-10 kg polymer/t DS. These results established the robustness and high treatment performance of the recuperative thickening process for the Pukete methane digesters. A regime to regularly clean the thickener fabric and to adjust the polymer dose to the changing nature of the digester feed sludge was required to maintain a high thickener performance.

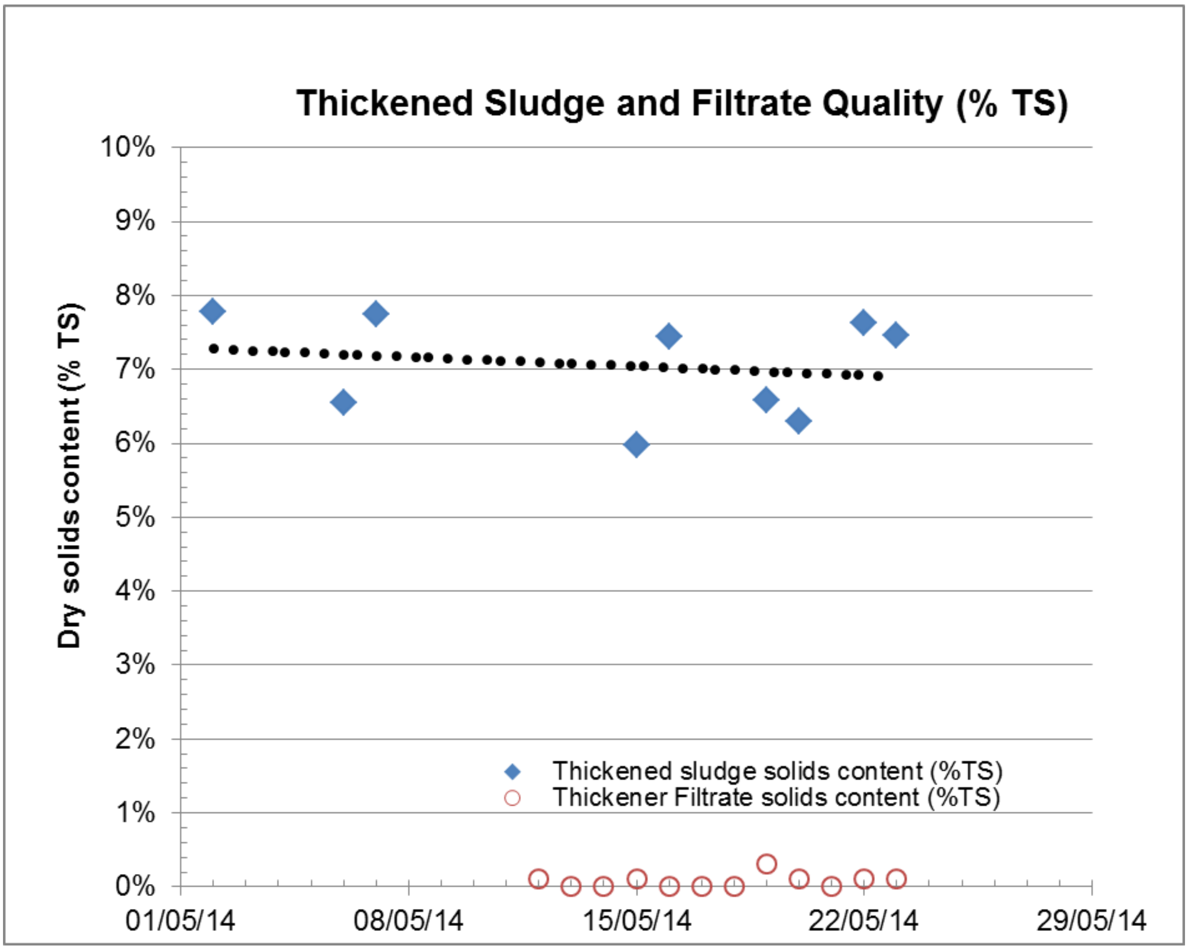

Figure 7: Recuperative thickener performance for methane digester tank MD2 with shunt pump mixing, ring main mixing and recuperative thickening after completion of the upgrade works. Data shown are in single tank operation mode treating the full acid stage effluent load of the Pukete plant. The solids content (%TS) results in samples recovered from the filtrate did not present increased variability when the digester solids content was increased from 2.6 % TS to 3 % TS.

The data in Figure 7 illustrate an attractive additional feature from recuperative thickening – the separation of the thickener input into a separately captured thickened sludge and a dilute filtrate. There are different piping configuration options available to capture additional benefits from production of high daily volume of a low solids content filtrate stream. This will be the subject of future operation optimization work of the digester upgrade. In the interim HCC has selected a methane digester upgrade configuration that recombines the thickener filtrate with the digester overflow in the digester supernatant sump using existing pipework.

4.2.5 SLUDGE FLOW TREATMENT CAPACITY

One commercial driver for the Pukete methane digester upgrade was the process design requirement to defer the capital expenditure needed for construction of a 3rd methane digester tank. Figure 8A below gives the projected Pukete plant biosolids volume growth between 2009 and 2028. The red line is the thickener throughput of the current plant at a thickener feed rate of 30 m^3/h and an effective thickener operation for 22 h/day. The treatment capacity of the installed recuperative thickening system operated at 30 m^3/h (85 % of its technical capacity of 35 m^3/h) was 110 % of the sludge flow treatment capacity expected to be required in 2028. The design provided sufficient operation flexibility for occasional thickener down times (maintenance or repair). The large volume of the methane digester tanks (2150 - 2200 m^3 per digester) was adequate as a flow buffer for thickener maintenance/repair down times in the order of 12 – 24 hours.

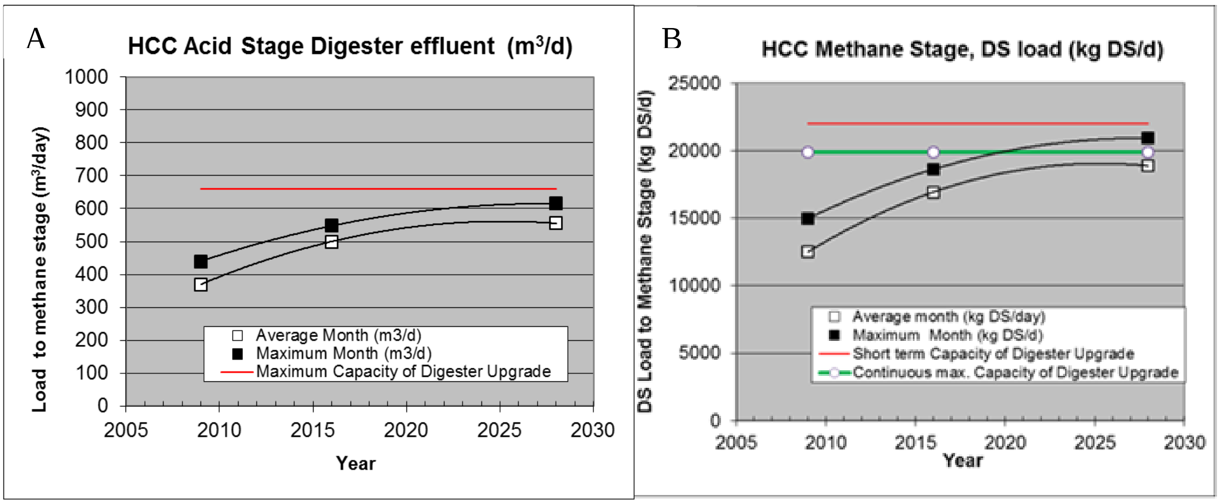

Figure 8: ***A*** *Sludge flow treatment capacity for the digester upgrade (red line) and design expectations at the outset of the project. The red line represents 85 % of the installed full sludge flow treatment capacity.* ***B*** *Dry solids (DS) load treatment capacity (green line) and design expectations at the outset of the project. Please note that the proven daily solids treatment capacity of the upgrade (green line) meets the average daily solids load forecast for the Pukete plant for months with maximum loads in the year 2020. The red line represents 85 % of the installed technical sludge solids treatment capacity and assumes that healthy active digester sludge is maintained in the methane stage digesters.*

4.2.6 SOLIDS TREATMENT CAPACITY

The process performance target for the digester upgrade was a treatment capacity for 17,700 kg TS/day when both digester tanks were connected to the recuperative thickener. The data given in Figure 8B are based on the digester MD2 performance measured after the upgrade and scaled for operation with 2 digester tanks and recuperative thickening. The data show that the installed upgrade has a proven sludge solids treatment capacity of 19,800 kg TS/day when 2 digester tanks are operated with recuperative thickening. This installed solids treatment capacity was adequate to allow for thickener downtime for repairs and maintenance and sufficient capacity for treatment of the expected daily TS load in months with maximum daily biosolids production.

5 OPERATOR EXPERIENCE WITH THE UPGRADED DIGESTERS

5.1 INSTALLATION

Photograph 1: Recuperative Thickener Installation (Photograph was taken during construction)

A new building was constructed to house the recuperative thickener, polymer make-up unit, and associated pumps and valves (Photograph 1). The motor control (MCC), site SCADA system terminal and variable speed drives were installed within a separate room of the new building.

The thickener building was maintained under slight positive pressure by the ventilation fans. The drum thickener was fully enclosed and the enclosure vented to atmosphere via to exhaust stacks through the building roof. In conjunction with the positive building air pressure, these vents allowed methane or hydrogen sulfide gas (potentially produced inside the thickener drum and sludge sump) to be discharged to atmosphere via the vents and prevented hazardous gas accumulation within the plant building. The space within the thickener building was not classified as a gas hazard zone, however, H_2S and CH_4 gas monitors were installed to enable alarms to be generated should dangerous concentrations of these gases accumulate.

5.1.1 DESIGN ENHANCEMENTS

Through the construction and commissioning of the upgrade a small number of modifications to the original design were made to improve ease of operation and reliability of the system. These included:

- Installation of a sludge flow meter on the discharge line from the thickened sludge pump. This change improved the thickener throughput monitoring and allowed the operators to identify periods when the thickened sludge pump output flow was occasionally below the optimal working point due to thickener control faults or occasional over-thickening of the sludge in the methane stage digester.

- Addition of an access port on the thickened sludge pump suction pipe work. This improved access to the thickened sludge sump for cleaning when occasionally excessive accumulation of “rag” material had been observed at this location.

- Fitting of a water supply booster pump to the polymer make-up unit. This eliminated the effect of water pressure fluctuations in the town supply water to the polymer make-up unit and improved polymer dosing consistency.

- Non-slip floor coating in the thickener building.

- The addition of a vacuum system for transfer of polymer powder from ground level to the elevated polymer hopper is currently investigated.

5.1.2 OPERATOR TIME REQUIRED

Municipal sludge digestion with recuperative thickening is ideally operated under daily digester operation conditions that are close to a “steady state”, e.g. no large daily variations in the total solids concentration in the digester liquor. Increased operational staff input was required during construction and commissioning when either non-routine operations upstream of the digesters led to unstable digester feed solid concentrations and rheology or when “thickening-up” of a digester was required in preparation for operation periods with only a single methane stage digester tank in operation. Closer attention to the thickener operation and more frequent sampling from the methane digesters in these periods ensured that the polymer dose was regularly adjusted to reflect changes in the nature and concentration of the feed sludge from the digesters. In these periods the Hamilton City Council (HCC) staff were assisted by Downer staff to reduce workload on HCC staff. Outside these periods, operator time input for the methane digesters with recuperative thickening was within the normal daily operator time requirements for the methane digesters.

5.1.3 RISK OF “OVERTHICKENING”

At digester liquor total solids concentrations above about 3.2% TS, digester mixing by the ring main system and the digester recirculation pump flows to the heat exchangers was reduced (pumps were designed to pump up to 3% DS). An increased blockage risk at the ring main mixing nozzles and through the heat exchangers was then experienced. The ‘rag’ content in the methane digesters has been observed to increase with the solids concentration and this was the suspected cause of the issues seen at the higher digester solids concentrations above 3 % TS. The installed recuperative thickening control system included automated flushing cycles to protect the ring main nozzles from accidental blockage by the thickened sludge. Additional sludge line flushing techniques were developed to clear blocked nozzles following rare events of accidental over thickening.

Spiire's recommendation of regular targeted "rag removal" through an increased frequency of sludge withdrawals from the base of the digester proved to be a successful way to manage the rag content within the digester system and prevented sludge line blockages.

5.2 EFFECTS ON REMAINING PLANT

5.2.1 GAS PRODUCTION

Figure 9 Specific Gas Production at the Pukete plant, Please note that recuperative thickening was practiced between March 2013 and June 2014

No signifiant impact on the overall gas production has been observed when methane digesters were operated with recuperative thickening (Figure 9). Gas production has historically shown significant seasonal variablity with decreased specific digester gas production especially when aluminum sulphate was added to secondary treatment for phosphorus removal (December to May inclusive).

5.2.2 PLANT POLYMER USAGE

The polymer dosing requirements at the centrifuges dewatering plant for the digested sludge were reduced by 38% (average) after the recuperative thickener had been commissioned. It is suspected that this was due to effect of residual surplus polymer in the thickener filtrate that was combined with the digester overflow and then pumped to the sludge dewatering. The average daily total polymer usage at the Pukete wastewater plant had increased by approximately 80% over the same period (data not shown).

Some of the increase in polymer usage in the Pukete wastewater plant was caused by external effects such as the additional sewage inflow to the plant and the additional solids load to the centrifuge dewatering plant during high rainfall events, additional solids load during digester sludge diversions in plant operation periods with a single methane digester tank and additional solids discharged in methane digester tank clean out. Our rough estimate is that the operation of the recuperative thickener had increased the total polymer consumption at the Pukete wastewater plant by approximately 65% when corrected for these external effects.

Optimization of the polymer dosing for the recuperative thickening will thus become now a key focus after the upgrade works are complete. Early trials indicate alternative polymer products could reduce the polymer consumption in the recuperative thickener by up to 50%.

5.2.3 POWER CONSUMPTION

Maximum power consumption of the capacity upgrade works including recuperative thickener motors, shunt pumps and ring main mixing pumps is estimated at approximately 45 kWel (about 1000 kwh/day). Shunt pump and mixing pump flow is on VSD control and timer control can be used if energy efficient mode of operation is desired. This maximum power consumption estimate should be seen in the context that the upgrade increased the digester capacity by about 100 % (i.e. the equivalent of 4.400 m^3 of additional well mixed new digester volume was created in the capacity upgrade). The specific power consumption for operation of the additional well mixed digester volume is thus about 10 W/m^3 of digester volume generated which is similar to the specific power consumption that would be required for the additional digester mixing energy if 4,400 m^3 of new constructed digester volume would have been added. Therefore there is no additional specific power consumption that can be attributed to the use of a digester capacity upgrade by improved mixing and recuperative thickening when compared to the capacity upgrade by construction of new digester tanks.

5.2.4 WATER CONSUMPTION

The installed recuperative thickener uses 7 m^3/hr of town supply water for continuous washing of the drum thickener fabric when the thickener is in operation. Town water supply was used to minimize the risk of blockages of the wash water nozzles during construction and commissioning. It is intended to change wash water supply to plant process water in the future with the addition of an in-line water filter to reduce the risk of thickener wash water nozzle blockages caused by river silt in the plant process water (coarsely filtered river water).

Town supply is also used for polymer make-up water to ensure the polyelectrolyte active sites are not occupied by clay particles or other water contaminants.

Recuperative thickener attributable town water consumption has averaged 100 m^3/day. This water consumption has approximately doubled the town water consumption of the Pukete plant.

5.2.5 DIGESTER SOLIDS DIVERSIONS

A conservative approach to methane digester loading during construction and commissioning when only one digester was in service meant 0-150 m^3/day of acid digester sludge was occasionally diverted directly to the centrifuge dewatering facility to reduce the methane digester load. Acid digester sludge dewaters very well so the overall effect of acid digester sludge diversions was a somewhat reduced polymer consumption of the centrifuge dewatering facility. However the dewatering centrate contained more soluble constituents and the biogas production of the plant is reduced when acid stage sludge is diverted. It is thus preferred to minimize acid digester solids diversion and to maximize the methane digester solids residence time and solids loading rate to achieve a high solids destruction efficiency and biogas production in the methane stage digesters.

5.2.6 CENTRIFUGE DEWATERING FEED SOLIDS

The solids content in the feed for centrifuges down stream of methane digesters showed greater variability since recuperative thickener had started operations. Dewatering centrifuge feed solids concentration variability was caused by effects of irregular hourly recuperative thickener filtrate flow to the centrifuge dewatering facility and greater variability of the hourly sludge volume discharged from methane digesters while the plant was commissioned. This effect was further exacerbated over some periods when acid digester sludge diversions where in place due to higher solids of acid digester sludge diverted directly to centrifuge dewatering.

In response to these challenges, the recuperative thickener operational hours were programmed by the operators more evenly spread throughout the day to reduce variability of centrifuge feed solids.

5.2.7 COST SAVINGS

The approach/design described in this paper created the equivalent of 4,400 m^3 of well mixed new digester volume by improving the efficiency of the existing digester tanks. It is estimated that the capital costs for construction of 2 new digester tanks for 4,400 m^3 of well mixed additional digester volume would be in the order of 200 % of the actual construction costs for the capacity upgrade by digester efficiency enhancements described in this paper. Therefore the approach described in this paper is a very cost effective solution to use existing wastewater treatment plant assets and gives Council the option for treatment capacity growth on the existing plant footprint (see Figure 1). In addition, the approach shown here provides “n + 1 digester tank redundancy” because the whole Pukete plant can be operated with only one methane digester tank when the recuperative thickener is used to its potential (see Figures 3- 7). This allows Council to “take down” one digester tank for maintenance purposes without consequences for the municipal treatment plant performance. The “digester capacity redundancy” could also be used outside of maintenance periods for treatment of additional trade waste from seasonal industries. Benefits for Council would be additional operation revenue from collection of gate fee income and production of additional biogas (used for electricity generation).

At this point it is too early to quantify potential WWTP operation cost savings that the digester capacity upgrade at the HCC Pukete plant can achieve. The optimum daily polymer dose/consumption has not yet been established. Routine operation of the upgrade works under reasonable stable plant load conditions can only be analyzed and optimized when both digesters have been fully upgraded.

5.3 DIGESTER CLEAN OUT

Digester No 2 was taken out of service and cleaned out first because it had shown less active digester volume during lithium chloride testing. Digester 2 had not been cleaned out for approximately 17 years. For the first 3 years of this period the Pukete wastewater plant had poor inlet screening efficiencies (18 mm bar screens) before the inlet screenings were upgraded in the year 2000. Upon emptying, digester No 2 was found to have accumulated approximately 1000 m^3 of rags and grit within the digester that needed to be removed. Significant fouling of gas sparger pipes in the biogas recirculation mixing system was also found (mainly from rags), which would have further contributed to the accumulation of rags and grit once it had become established.

Digester No 1 was found to have had approximately 300 m^3 of accumulated rags and grit. Digester 1 had not been emptied and cleaned out for approximately 15 years Digester 1 had also benefitted from 12 months of additional shunt pump mixing prior to the cleanout which greatly improved digester mixing in the peripherals of the digester and was possibly able to re-suspend some of the solids accumulation at the bottom of the side walls.

5.3.1 METHOD OF DEWATERING

A vacuum assisted belt press was used for digester No 2 emptying and a compression only belt press used for digester No 1 emptying. Generally speaking solids capture was greater for compression only belt press. It is thought that a vacuum belt press may have allowed too much of finer inert material to pass through belts.

Photograph 2 Truck Mounted Hydrocare Belt Press - emptying of methane digester No 1-June 2014

5.3.2 HANDLING OF FILTRATE

Vacuum belt press filtrate from emptying of methane digester No 2 was discharged directly to the plant head works. Belt press filtrate caused at times high solids and organic loading to the plant head works and presented a risk of process issues within primary and secondary treatment from high load or shock loading effects.

The decision was made for methane digester No 1 emptying operations to direct belt press filtrate to the onsite lagoon to reduce the impact on the plant

6 CONCLUSIONS

In conclusion, this paper has demonstrated that the HCC digester upgrade project has achieved all Council objectives that were specified at the outset as key design requirements and Council goals. The innovative approach and technology combination chosen by Downer and Spiire has demonstrated the following key benefits to Council.

(A) The treatment capacity and digester performance upgrade was achieved at approximately 50 % of the capital costs for the equivalent capacity upgrade through construction of new digester tanks.

(B) The achieved n+1 redundancy in the number of independent methane digester tank units gave Council the "freedom to operate" and ability to take down a methane digester for service/maintenance when required and without the costs for construction of a 3rd digester tank.

(C) The solids treatment capacity increased from about 10,000 kg TS/day to about 20,000 kg TS/day.

(D) The sludge flow treatment capacity increased from about 350 m^3/day TS/day to about 700 m^3/day.

(E) Improved digester process robustness and methane digester sludge activity was achieved. This allowed methane stage operation at very high loads, very short hydraulic residence times, stable pH and low levels of VFA in the digester effluent. The inherently improved digester process robustness with recuperative thickening is a key point of the capacity upgrade concept that has been proven. Digester capacity upgrades with recuperative thickening are suitable for WWTP's with a high degree of automation because increased process robustness reduces operation risk and operator time input into the methane stage digester operation.

(F) The added power consumption for operation of the existing methane digesters with recuperative thickening at doubled capacity was less than 10 W/m^3. This was less than the expected added power consumption if the doubled capacity would have been achieved with construction of 4,400 m^3 of new methane digester volume.

(G) The available digester capacity at HCC after the upgrade was sufficient to defer the decision about the construction of additional digester tanks until about the year 2020.

Further experience with the operation of the digester capacity upgrade at HCC will allow to quantify the long term commercial benefits that were derived for HCC from this project. It is important to note that the technology and concepts proven here are equally suitable for cost effective treatment of industrial wastewater and trade waste at high loading rates and low hydraulic residence times.

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