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Solids digestion pilot study at Teys Bros Beenleigh

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Executive Summary

This report addresses the Biosolids TPAD Demonstration plant constructed and operated as part of MLA/AMPC project A.ENV.0068. The project was a collaboration between The University of Queensland (UQ), Meat and Livestock Australia (MLA), Australian Meat Processor Corporation (AMPC), Environmental Biotechnology CRC (EBCRC) and the Queensland Government. This report details current project achievements; however the project is ongoing, continuing as A.ENV.0099.

The EBCRC/UQ Biosolids demonstration plant was originally commissioned in August 2010 and operated successfully for 1 year to treat wastewater and sludge associated with the generation and handling of paunch solid waste (Stage 1). The demonstration plant was able to treat 5 – 6 m^3 wastewater per day producing over 15m^3 of biogas. The biogas composition was typically 63% methane (CH_4) and 37% carbon dioxide (CO_2), this corresponds to 10m^3 of CH_4 per day or ~300 L/kg VS added. The combination of biogas production and low VFA concentrations in the digester effluent were a good indication of a healthy and stable process. Biogas was used to fire an industrial gas hot water system and offset heating requirements of the demonstration plant. However, due to the low concentration of organic material present in paunch wastewater (<1%) biogas production during this first stage of operation was not sufficient to fully offset heating requirements and/or generate excess energy for the host plant.

In 2011, the demonstration plant was upgraded with the implementation of an automated solids handling system capable of feeding paunch solid waste (Stage 2). This enhanced capacity of the demonstration plant to assess high-solids feed levels and demonstrate process performance. Stage 2 is an ongoing activity (MLA project A.ENV.0099), however, the demonstration plant was operated for 3 months stably on a higher solids feed (~2-5% feed) before operation of the host site was shut down for maintenance. Solids destruction levels were high, with laboratory tests returning a VS destruction of approximately 65%, and in-reactor performance achieving >60% (based on 3 calculation methods). This indicates that full scale implementation of TPAD would be successful and would allow every 10 tonnes of paunch solid waste to be reduced to 4 tonnes of organic fertilizer. Biogas production both in the lab and in-reactor are averaging 240 L CH_4/kg VS loaded (1 atm/15°C), this corresponds to 9 MJ energy available to offset energy requirements of treatment or host plant operations.

Overall installed costs of the demonstration plant were approximately \$350,000 and costs were approximately 65% process vessels (\$1000 per m^3 installed volume), and 35% ancillaries (\$500 per m^3 installed volume). Current heat load is 2.4 kWh/m^3/d. Electrical input is very high at approximately 2.4 kWh/m^3/d, however, this could not be optimised due to the size of the demonstration system. Full-scale systems normally operate at 0.1-0.2 kWh/m^3/d. We estimate that ongoing operations would require operator input at 0.25 FTE, including a solids handling system. Based on biogas production yields in the demonstration plant, an organic load of 1.2-1.4 kgCOD/m^3/d is required to meet the energy demand of an optimised demonstration plant. The current demonstration plant will handle feed material concentrated up to 6% solids, and/or reactor loading up to 2 kgCOD/m^3/d. This confirms that the demonstration plant is able to generate excess energy to offset requirements of the host plant.

Currently, the operating limits of the demonstration plant have not been determined. Extension of the project is recommended to identify operating limits and identify if other solid organic solid waste stream available at a meat processing facility can be treating using co-digestion in the demonstration plant.

Contents

Glossary

AD	Anaerobic Digestion
AL	Anaerobic Lagoon
AMPC	Australian Meat Processor Corporation
BMP	Biological methane potential
BNR	Biological Nutrient Removal
CBA	Cost Benefit Analysis
CH_4	Methane
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
EBCRC	Environmental Biotechnology Co-operative Research Centre
EHWS	Electric Hot Water System
GHWS	Gas Hot Water System
HRT	Hydraulic Residence Time
IVAD	In-Vessel Anaerobic Digestion
MLA	Meat and Livestock Australia
N	Nitrogen
P	Phosphorus
PLC	Process Logic Control
SRT	Solids Retention Time
TPAD	Temperature Phased Anaerobic Digestion
TS	Total Solids
UQ	The University of Queensland
VFA	Volatile Fatty Acids
VS	Volatile Solids

1 Introduction

1.1 Background

In the Australian meat processing industry, there is strong ongoing interest in anaerobic digestion (AD) of waste solids, particularly paunch and DAF sludge. This is partly driven by an established need for an alternative to current waste sinks, which are largely composting, direct land application, and landfilling. Alternative waste sinks will address costs and risks associated with current disposal applications, which are increasing either due to implementation of policy (e.g., Qld Landfill Levy), regulations around pathogen control in land application and composting, and potential social impacts of direct disposal or land application. AMPC and MLA are actively exploring anaerobic digestion as a potential new sink, as well as other options such as thermal destruction or charring, which are likely to have specific strengths and weaknesses (e.g., complexity, capital cost); but are not addressed in this project.

This report is for the Temperature Phased Anaerobic Digestion (TPAD) demonstration plant constructed and operated as part of MLA/AMPC project A.ENV.0068. The project was a collaboration between The University of Queensland (UQ), Meat and Livestock Australia (MLA), Australian Meat Processor Corporation (AMPC), Environmental Biotechnology CRC (EBCRC) and the Queensland Government.

1.2 Objectives

The larger project was based on the technology of TPAD and is divided into Sub-project 1: laboratory work, and development of key IP, and Sub-project 2: Pilot scale demonstration facility. There were 8 formal project research milestones to be completed as part of the initial project. All milestones are now complete and have been reported separately to MLA/AMPC and EBCRC. The scientific objectives of the project were:-

- Investigate the mechanism of pre-treatment, which was thought to be microbial.
- Optimize the pre-treatment method to provide a maximum level of final solids destruction.
- Establish Class A stability by pathogen testing, such that a continuous process can be used.

The overall goal of the project was to produce a technology package that has a relatively low capital loading, and achieves a product with the following specifications:-

- Class A stability biosolids product
- Low odour and good handling characteristics (de-waterability of >20% on belt press and >30% on centrifuges)
- Net electricity generation
- Total biosolids disposal (NPV basis) of <$50/wet.

This report addresses MLA funded research as part of Sub-project 2: Pilot scale demonstration facility, including the design and operation of the demonstration plant.

2 Demonstration Plant Description and Design

2.1 Design Summary

The EBCRC/UQ Biosolids demonstration plant is based on a Temperature Phased Anaerobic Digestion (TPAD) process. TPAD is a two stage thermophilic-mesophilic treatment process. The first stage is operated at higher temperature (>50°C), with a 2-4 day retention time while the second stage is operated at moderate temperature (~35°C) with a 12-20 day retention time. The first stage is designed to destroy pathogens and enhance hydrolysis to condition the organic material and improve digestibility, while the second stage is designed to produce methane which can be used for renewable energy generation and stabilised organic residues (e.g. biosolids) which can be reused in agriculture. A process flow diagram for the demonstration plant is shown in Figure 1. There were two stages of construction, testing and operation of the demonstration plant. Stage 1 was designed to operate on wastewater and wastewater sludge (<1% solids). Stage 2 was designed to operate on solid waste slurry (2-5% solids). The configuration of the feed tank was the only variation in the process operation between stages.

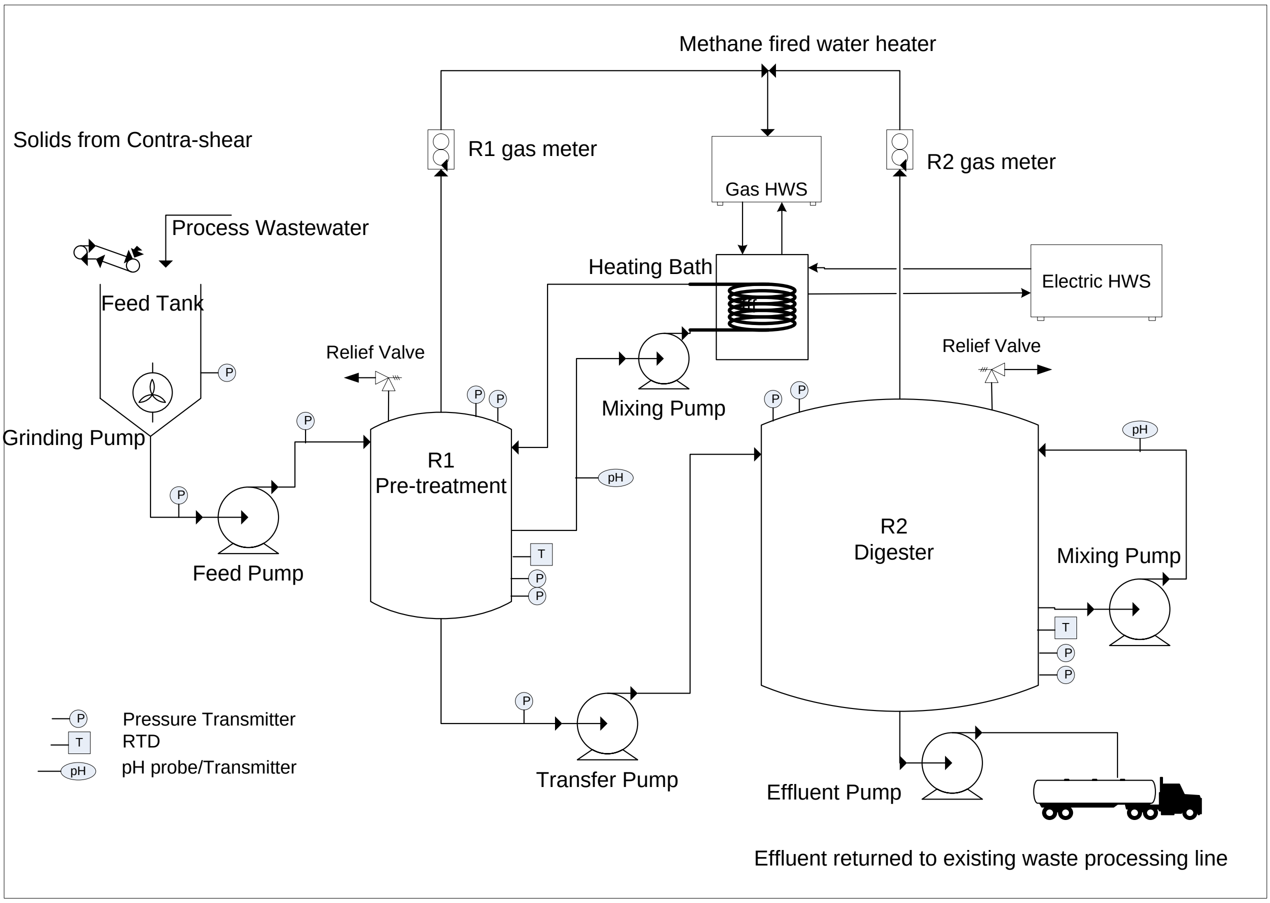

Figure 1: Process flow diagram of TPAD demonstration plant installed at an Australian Meat Processing Facility

The demonstration plant was monitored and controlled using field sensors and a process logic control (PLC) system. The process control system contained two alarms levels in the case of abnormal plant operation. Alarm level 2 (L2) stops feed processes and transfer processes, but allows mixing and heating operations to continue. Alarm level 1 (L1) initiates a plant shutdown but allows monitoring and recording of process variables. A list of monitoring operation and alarm trigger events is shown in Table 1.

Table 1: List of key measurements and control processes

Control Event	Control Process
Feed Tank	Monitored via pressure transmitters and logged. During feed preparation, the feed tank level is used to measure solid paunch and determines the volume of process water required. Multiple L2 alarms are attached to the feed tank: Level/volume, feed prep timeout, feed prep feedback.
Feed Tank Mixing Pump	The Mixing pump fluidises and breaks agglomerates in the feed solids. A current draw monitor is placed in the circuit to check operation, if no flow then L2 alarm is initiated.
Feed Pump Suction pressure	Pressure of the pipeline on the suction side of the feed pump is monitored. A low pressure reading indicates a blockage and initiates a L2 alarm.
Feed Pump Discharge Pressure	Pressure of the pipeline on the discharge side of the feed pump is monitored. A high pressure reading indicates a blockage and initiates a L2 alarm.
Feed pump, transfer pump, waste pump	The feed pump, transfer pump and waste pump contain feedback connections to the PLC. If pump operation doesn't match the control process a level 1 alarm is initiated.
Mixing pumps	The reactor 1 and reactor 2 mixing pumps contain feedback connections to the PLC. If pump operation doesn't match the control process a level 1 alarm is initiated.
Reactor 1 Temperature	Reactor 1 temperature is monitored using an RTD. Low temperature initiates the electric HWS.
Reactor 2 Temperature	Reactor 2 temperature is monitored using an RTD. No control operations and no alarms are linked to this measurement.
Reactor Tank Level	Reactor level/volume is monitored using pressure transmitters on the side of the tank. There are two alarm stages for both high and low levels.
Reactor Headspace Pressure - Low	Reactor pressure is monitored using pressure transmitters on top of the tank. There are two alarm stages for low pressure levels/tank vacuum.
Reactor Pressure - High	Reactor pressure is monitored using pressure transmitters on top of the tank. When the pressure increases to the setpoint, the gas HWS system is triggered. There are high pressure alarms and a safety release.
Reactor pH	Reactor pH is monitored and logging via recirculation lines in each reactor. No control operations and no alarms are linked to this measurement.

2.2 Plant Geography/Foundation

The demonstration plant was constructed on the edge of a small creek increasing the risk of flooding and erosion. Detailed soil testing analysis was performed prior to building on the site and highlighted the requirement for extensive stabilisation of the foundations for the demonstration plant.

The foundation of the plant is a steel reinforced concrete slab rated to a pressure of 25 MPa, it is supported by concrete pylons sunk to the bed rock. The main demonstration plant occupies a footprint of approximately 10 m x 12 m, and has a total area of 73 m^2 as indicated in Figure 2 (the feed tank is located separately to the main plant). Detailed structural design of the concrete foundation is dependent on soil conditions and will therefore be site specific.

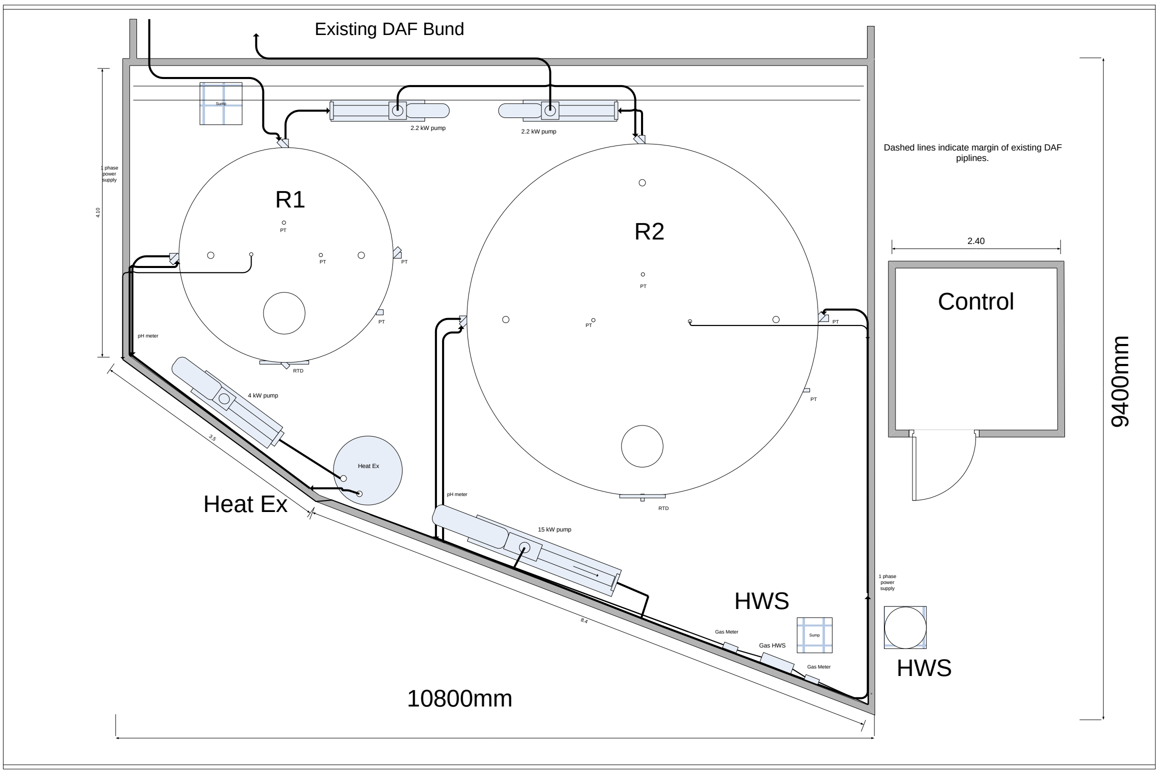

Figure 2: Layout and footprint of TPAD demonstration plant installed at an Australian Meat Processing Facility

The demonstration plant foundation is surrounded by a 1m high bund made of concrete filled blocks. The bund is designed to contain the contents of the reactors should a catastrophic pump/pipe failure occur, the bund volume will retain the total operational contents of the largest reactor with 10% volume of the bund volume to spare. Electronic equipment within the bund area is raised on support bases to prevent damage if a bund flood event occurs.

2.3 Process Vessels

2.3.1 Thermophilic Pre-treatment Vessel (R1)

The pre-treatment vessel, designated R1, is a cylindrical vessel constructed from 304 stainless steel (3mm), capacity and dimensions are approximately 20 m^3 (3 m diameter, 3 m height, raked roof). The tank is operated at 10 m^3 providing a retention time of 2 days at a feed rate of 5 m^3 per day. The pre-treatment vessel is oversized to allow flexibility in pre-treatment residence time during research operations.

The pre-treatment vessel is designed to operate at thermophilic temperatures between 50°C and 70°C. Mixing in the pre-treatment vessel is achieved by re-circulation through external pumps. Temperature in the pre-treatment vessel is maintained by circulation through an external shell and tube heat exchanger as part of the mixing system. The location of feed points, withdrawal points and re-circulation/mixing points is shown in Figure 3.

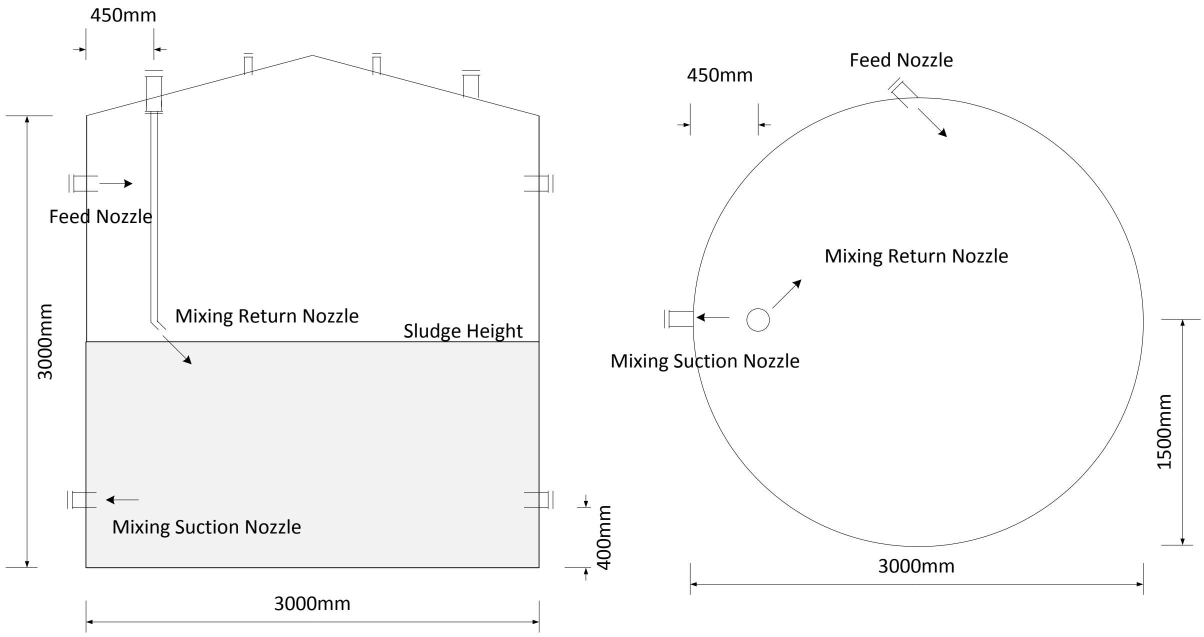

Figure 3: Pre-treatment tank: dimensions, location of feed points, withdrawal points and mixing nozzles

The pre-treatment reactor is designed to run at positive pressure to reduce the possibility of a methane/air mixture forming. Standard operating pressure is 8-12 kPa (with emergency relief at 17 kPa), and according to Australian standard AS 1210-2010 this vessel is not classed as a pressure vessel.

2.3.2 Anaerobic Digester (R2)

The anaerobic digester, designated R2, is a cylindrical vessel constructed from 304 stainless steel (4 mm), capacity and dimensions are approximately 95 m^3 (5 m diameter, 4.8 m height, raked roof). The tank is designed for operation at 80 m^3 providing a retention time of 16 days at a feed rate of 5 m^3 per day. The ratio of liquid volume to total tank volume (85% liquid volume) follows heuristics for anaerobic digester design and operation. The geometry and dimensions of anaerobic digestion vessels are flexible and often determined by factors such as the mixing mechanism and/or footprint available e.g. digesters mixed using gas re-circulation often designed to be wide and shallow, while digesters using mechanical agitation or pump mixing may be conical or egg shaped [1].

The anaerobic digester is designed to operate at approximately 35°C. Temperature in the digester is maintained by the addition of heated effluent from the pre-treatment reactor, there is currently no independent temperature control system in the digester, however this capability is strongly recommended for future installations. Mixing in the digester is achieved by re-circulation through external pumps. The location of feed points, withdrawal points and re-circulation/mixing points is shown in Figure 4.

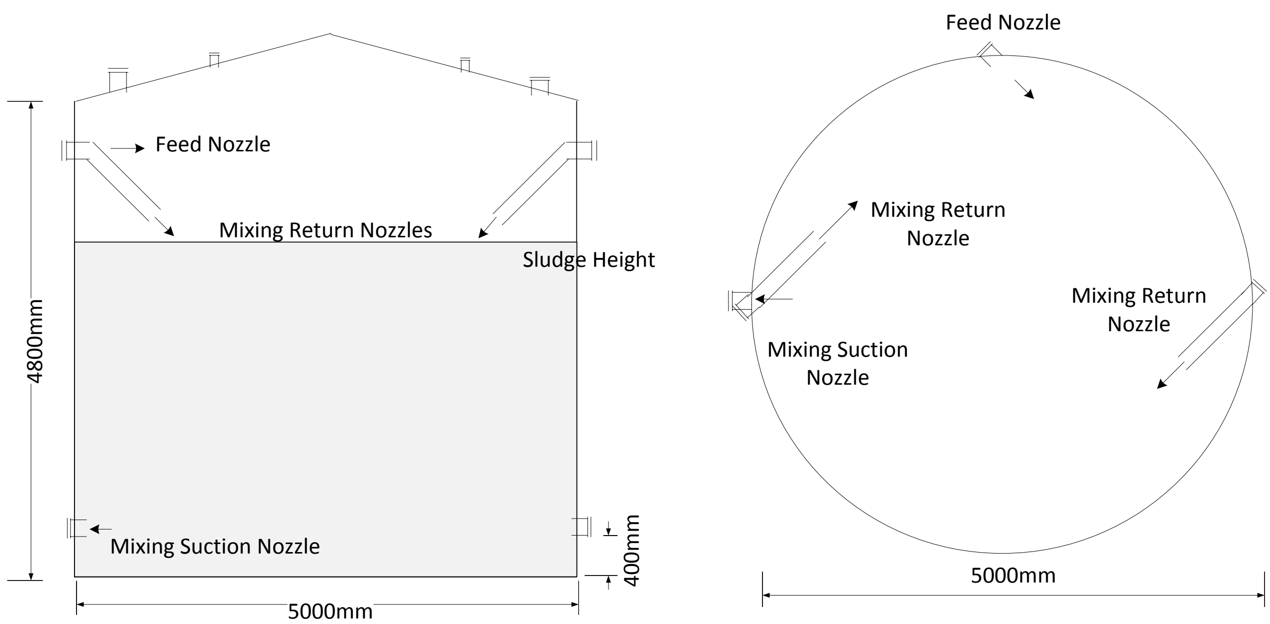

Figure 4: Anaerobic Digester: dimensions, location of feed points, withdrawal points and mixing nozzles

Similar to the pre-treatment reactor, the anaerobic digester is designed to run at positive pressure to reduce the possibility of a methane / air mixture forming. Standard operating pressure is 8-12 kPa (with emergency relief at 17 kPa), and according to Australian standard AS 1210-2010 this vessel is not classed as a pressure vessel. Frangible roof evaluation were conducted to determine the failure conditions of the tank and failure characteristics, the testing indicated that the digester roof was the weakest point in the structure and may fail at pressures above 18 kPa.

2.3.3 Heat Exchanger

Temperature control in the pre-treatment reactor was achieved using a shell and tube style heat exchanger. The heat exchanger comprised of a single stainless steel coil (50 mm diameter x 25 m length) in an 800 L stainless steel tank. Wastewater/sludge from the pre-treatment reactor was pumped continuously through the tube side (coil), while hot water flows through the shell side (tank). The water in the shell of the heat exchanger was primarily heated using a gas hot water system (GHWS) running on biogas produced by the demonstration plant. An electric hot water system (EHWS) system was connected as a back-up heat source. Reactor heating via an external circulation loop is strongly recommended in future installations with a variety of commercial heat exchangers available.

Figure 5: Shell and tube heat exchanger used to heat TPAD pre-treatment reactor

2.4 Feed Collection Systems

2.4.1 Wastewater Feed Collection

Feed operations will be unique to each processing site and each treatment facility. This section describes the wastewater collection system was used during Stage 1 plant operation. The wastewater collection system collects paunch wastewater separated from paunch solids in a rotating drum screen (Contrashear). The wastewater was continuously collected and fed to a 1,400 L buffer tank (approximate residence time 1 hr). Initially, when the plant was operated in 2010, the buffer tank was mixed regularly (10 mins on and 10 mins off) to minimise settling and maintain wastewater feed that was representative of wastewater produced at the host site. However, when the plant was re-started in 2011 the buffer tank was operated as a clarifier and solid particles were allowed to settle and collect in the tank. The settled sludge was then fed to the TPAD plant.

Figure 6: Wastewater feed collection system at TPAD demonstration plant host site in 2010.

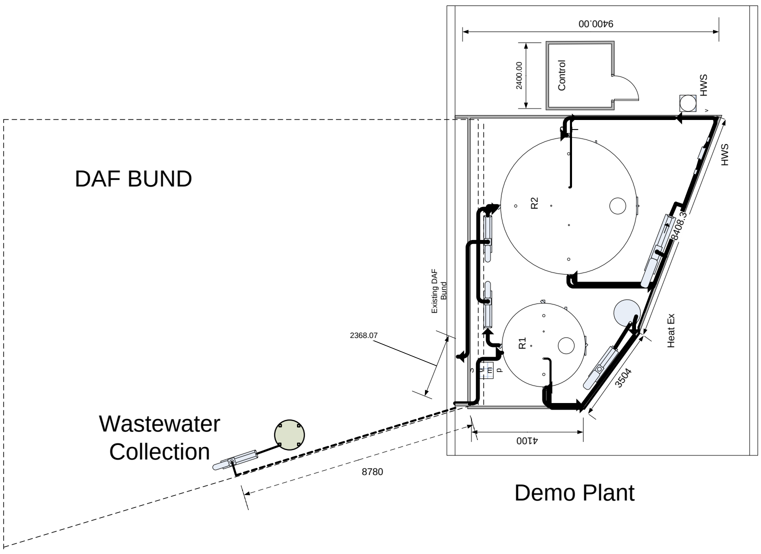

Figure 7: Layout of wastewater handling system within demonstration plant host site in 2010.

2.4.2 Solid Waste Collection System

This section describes the solid waste collection system used during Stage 2 of plant operation. The solid collection system is an automated process to collect de-watered paunch solids directly from the outlet of a rotating drum screen (Contrashear). The system uses a PLC controlled pneumatically activated ram which actuates a hinged chute, the chute opens and intercepts dewatered solids leaving the Contrashear. The dewatered solids (10-12% total solids) slide into the feed tank via a stainless steel chute and are diluted with process water to the desired solids concentration (approximately 4% desired). Dilution water is added at the top of the chute to help the solids slide down the chute. The solids collection chute installed at the demonstration facility is shown in Figure 8, and the position of the solids feed system within the waste handling area at the demonstration plant host site is shown in Figure 9. The open tank design allows for alternate types of solid waste produced on site to be fed manually to the demonstration plant as required.

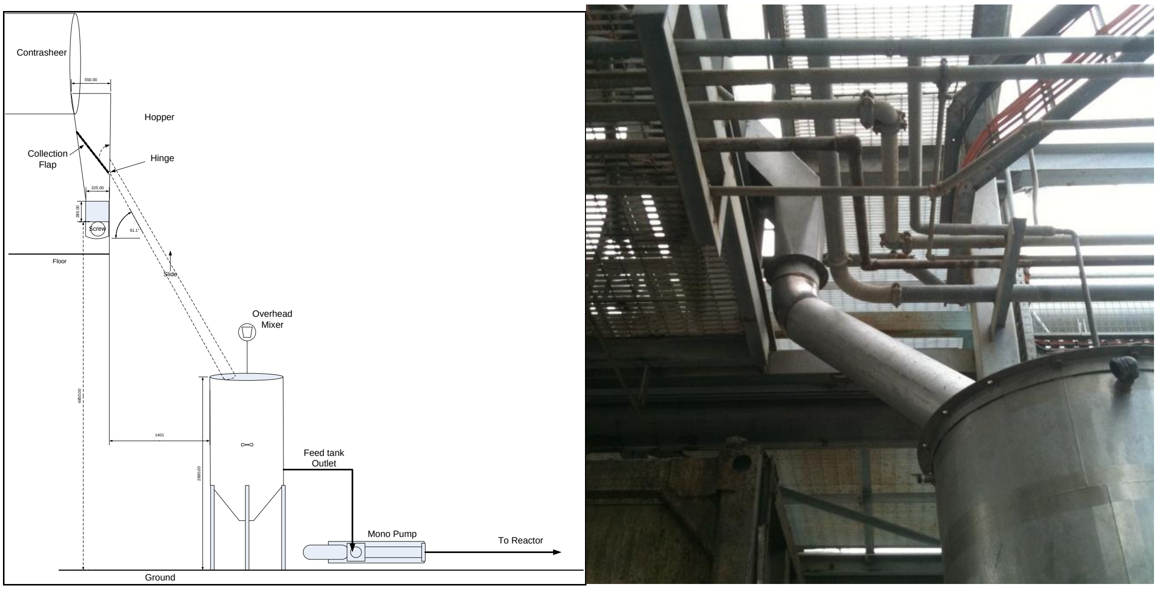

Figure 8: Contrashear and collection chute at demonstration plant host site in 2011

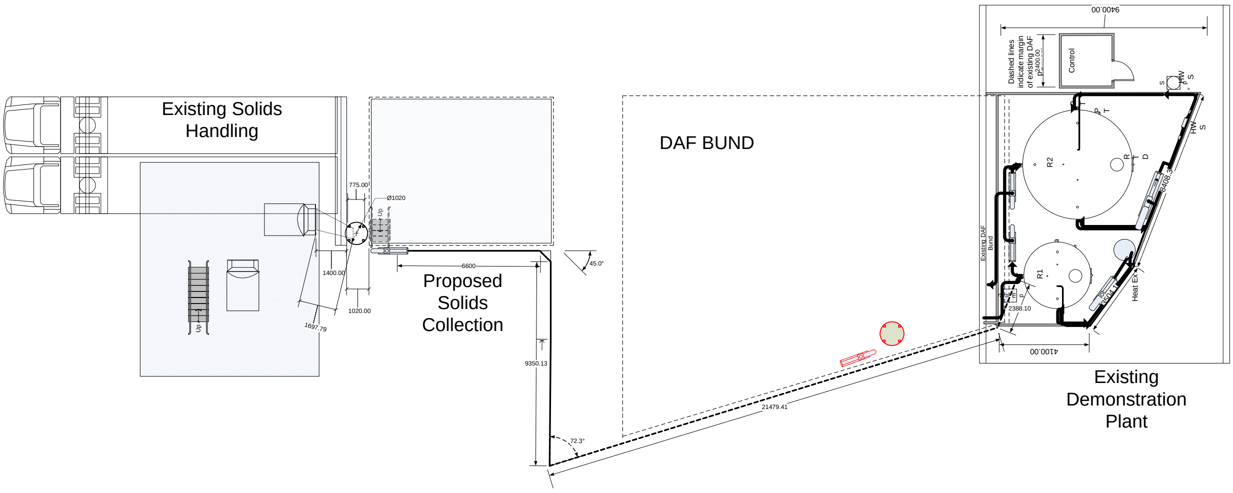

Figure 9: Layout of Solids Handling System within demonstration plant host site in 2011

Full scale installations at processing sites using wet-paunch handling processes should consider using the ‘combined green’ waste slurry directly as produced (approx. 3-5% solids). Full scale installations at processing sites using dry-dump paunch handling will need to dilute the paunch before adding to the process.

2.4.3 Pumps

Material handling and transfer is a critical component of the demonstration plant operation. Five 3-phase Mono progressive cavity pumps are utilised for feed, transfer and mixing operations. The Mono pumps were selected for their low shear, longevity, resistance to blockage and their relatively consistent pump rate under variable pressure conditions. Small auxiliary pumps are also used on the shell side of the heat exchanger. The feed preparation tank utilises an overhead impeller style mixer with a small electric motor. Table 2 shows a summary of pump type and capacities.

Table 2: Summary of electrical pumps installed at TPAD demonstration plant

Equipment	Installed capacity	Pumping capacity (max)	Type
Feed mixing	0.6 kW	Mixing - Unknown	Overhead shaft mixer
Feed Pump	2.2 kW	4.5 m^3/hr	Mono-Progressive cavity pump
Transfer Pump	2.2 kW	4.5 m^3/hr	Mono-Progressive cavity pump
Waste Pump	2.2 kW	4.5 m^3/hr	Mono-Progressive cavity pump
R1 mixing	4 kW	24 m^3/hr	Mono-Progressive cavity pump
R2 mixing	15 kW	80 m^3/hr	Mono-Progressive cavity pump
Electric hot water pump	~60W	~30lpm	Centrifugal
Gas hot water pump	~60W	~30lpm	Centrifugal

Figure 10: Paunch solids (left), Paunch solids treated using sewage grinding pump for 5 mins (middle), upgraded overhead mixing system (right).

3 Processing Performance

3.1 Summary

The demonstration plant was designed to treat paunch waste at an organic loading rate of 1 to 2 $kg/m^3/day$. Over 60% Volatile solids destruction has been achieved during operation with methane yields of ~240 L/kg VS. The biogas has been used to fire an industrial gas hot water system without treatment or conditioning.

3.2 Operating Mode

The demonstration plant operated in semi-continuous mode. There were 10 feed events per day, five days per week. Feed events commenced at 8am Monday to Friday and were scheduled at intervals of 1h 45mins (start time to start time). Feed events occurred as a sequential process where waste material was first pumped from R2 and returned to the onsite waste handling pipeline, pre-treated material was then transferred from R1 to R2, and finally fresh feed was pumped into R1. The total time to complete a full feed sequence was approximately 20 mins. There was an 8 hour gap between the last feed event of a day and the first feed event of the next day. Solid paunch degrades slowly, as a result the response to feed events is slow and there is no pattern linking gas production and the daily feed schedule. However, gas production does decline over the weekend, when feed is not available for two days.

A full scale plant could be operated as continuous or semi-continuous with no significant impact on process stability. The availability of feed material will be determined by the operating shifts of each processing plant. The recommended operating mode of the TPAD process would be to feed continuously or to minimize the time between feed events during operating shifts. Processes lines should then be flushed at the conclusion of each day. This strategy would assist in reducing blockages from solid material settling in process lines between feed events.

3.3 Feed Material

The demonstration plant treats green waste. The green waste consists of umbrella wash/paunch and waste from the ante-mortem yards. The waste stream was screened to separate wastewater and solid paunch cake. The wastewater is treated in an anaerobic lagoon, while the solid paunch is transported off site for treatment. Both the wastewater and the solid waste are highly variable, compositions are shown in Table 4.

Table 4: Characteristics of green waste from host site (error margins indicate 95% CI)

Characteristic	Green Wastewater		Paunch
	2010[a]	2011[b]	2011[c]
Total Solids (g/L)	7 ± 6	14 ± 10	22 ± 5
Volatile Solids (g/L)	6 ± 5	10 ± 9	19 ± 5
Total Chemical Oxygen Demand (g/L)	12	21	25 ± 8
Soluble Chemical Oxygen Demand (g/L)	1.7	1.1	0.6 ± 0.3
Volatile Fatty Acids (mg/L)	630	820	

[a] based on 48 measurement events **[b] based on 43 measurement events**

[c] based on 27 measurement events

3.4 Lab Based Performance

Biological methane potential (BMP) for green wastewater and paunch cake has been evaluated using batch tests in the laboratory [2, 3]. The BMP is an indication of the potential for energy recovery from a material and the solids destruction during treatment (and associated reduction in disposal/reuse costs). Cumulative methane production from the Paunch solids and paunch wastewater samples are shown in Figure 12. Biochemical methane potential production from the wastewater sample was ~340 L $kgVS^{-1}$; this is much higher than the methane potential for paunch solids (~240 L $kgVS^{-1}$). Lower methane potential from paunch solids is likely the result of an increase in lingo-cellulosic material with inherently lower degradability. Degradability of the paunch solids was modelled at 50-55%, therefore up to 55% of volatile solids destruction could potentially be achieved in the demonstration plant with a sufficiently long treatment time. Based on the degradation rate of paunch, volatile solids destruction of 30% was expected using the demonstration plant configuration (2 day pre-treatment and 16 day digestion). However, this is based on a relatively poor hydrolysis rate coefficient at 35°C, and higher values may be achieved in the demonstration plant due to thermophilic pre-treatment. Overall, the laboratory tests are favourable and suggest paunch cake has a similar degradability to municipal sewage sludge.

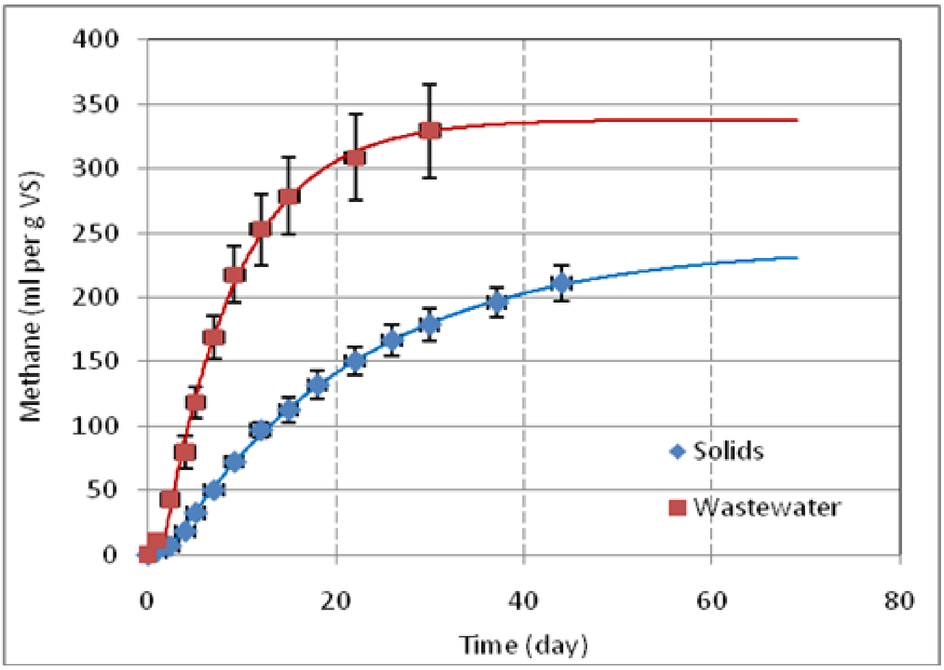

Figure 11: Methane production (triplicate BMP tests) for paunch solids and paunch wastewater from host site

3.5 Demonstration Plant Performance

3.5.1 Stage 1: Paunch Wastewater

Volatile Solids (VS) destruction is a key indicator used to assess the performance of anaerobic digestion processes. VS concentrations in the demonstration plant are shown in Figure 12. The VS concentrations are highly variable; this is a flow on effect from variability in the feed characteristics.

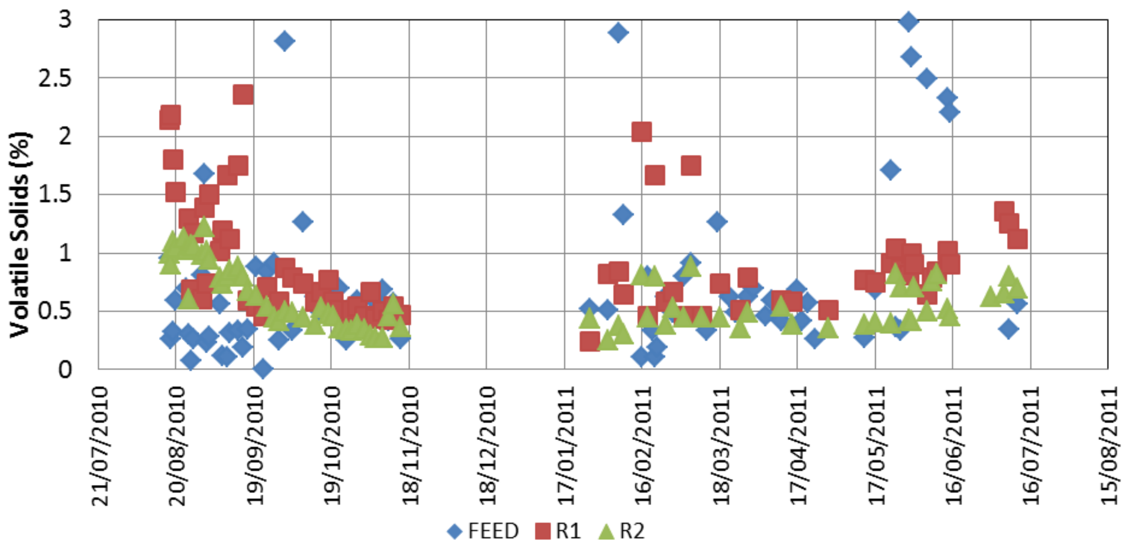

Figure 12: Volatile Solids Concentrations in the Feed, thermophilic pre-treatment (R1), and digester (R2).

The variability in VS concentrations makes assessments of VS destruction in the demonstration plant difficult. Preliminary estimates of VS destruction are based on a mass balance equation and the Van Kleeck method; the results are shown in Figure 13. The mass balance equation is sensitive to variations in feed concentration and poor mixing, but not feed composition. The Van Kleeck method is sensitive to feed composition, but not concentration or mixing. Ideally, estimates of VS destruction would be similar using the two methods; however the calculations in Figure 13 show both methods to be highly variable between 0-70% and poorly correlated.

Biogas production data from the demonstration plant is shown in Figure 14. Biogas composition was typically 63% CH_4 and 37% CO_2. On average over 15m^3 of biogas, corresponding to 10m^3 of methane was produced per day; this corresponds to ~300 L/kg VS_{added}. The biochemical methane potential for paunch wastewater estimated from batch testing is 300-350 L/kg VS; this indicates that a high fraction of degradable material is removed in the demonstration plant.

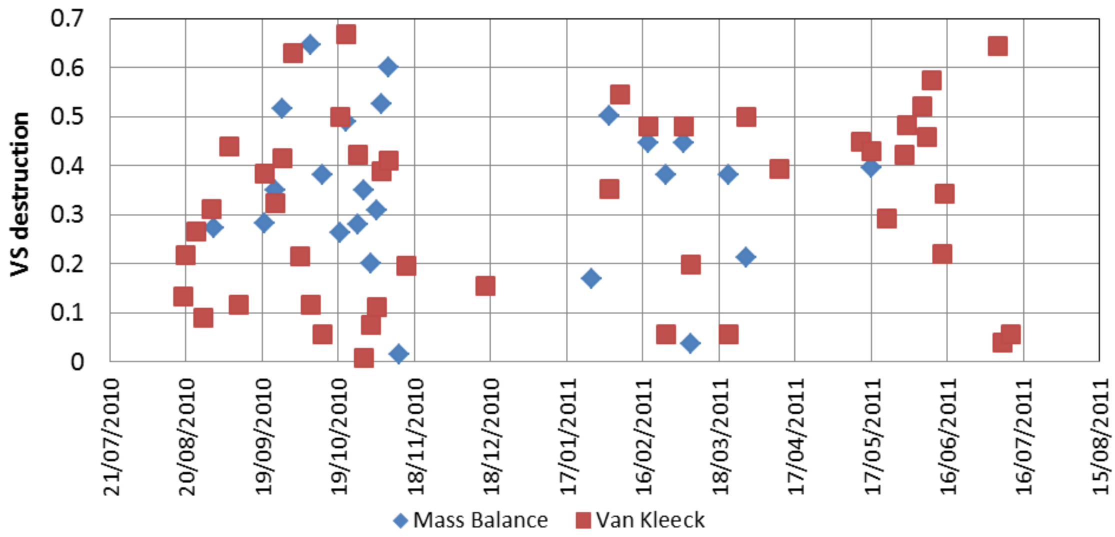

Figure 13: VS destruction across the digester (R2) calculated using a mass balance method and the Van Kleeck method.

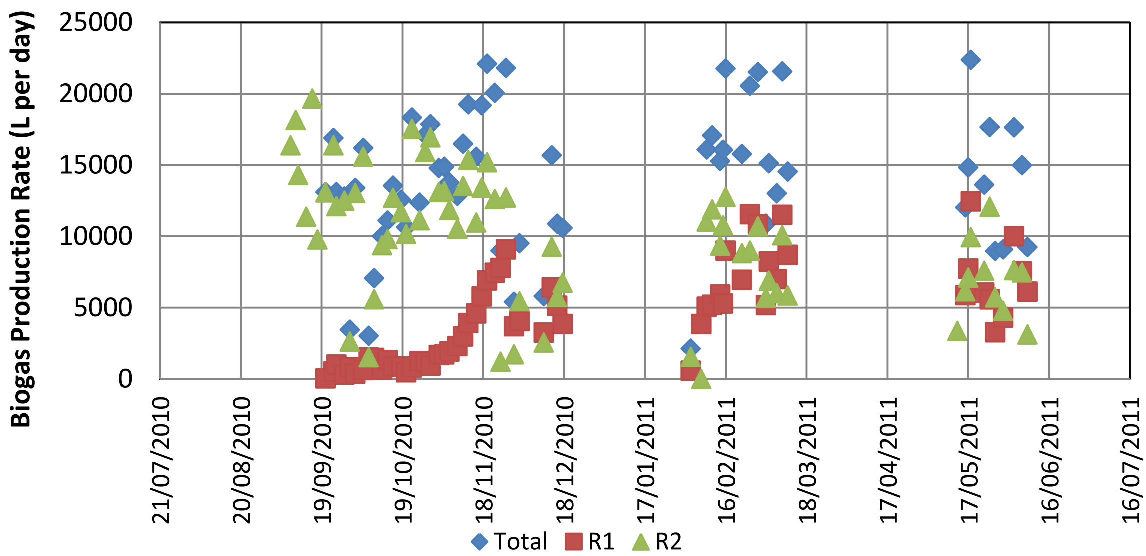

Figure 14: Biogas production from the Demonstration plant thermophilic pre-treatment (R1), and digester (R2).

Volatile fatty acids (VFA) are an intermediate product of anaerobic digestion resulting from hydrolysis and fermentation of organic material. VFA concentrations in the feed, pre-treatment (R1), and digester (R2) effluent are shown in Figure 15. The VFA concentration in the pre-treatment effluent WAS generally higher than the VFA concentration in the feed material suggesting that hydrolysis and fermentation are occurring during pre-treatment. Hydrolysis is often a rate limiting step in anaerobic digestion and improved hydrolysis is a key part of the pre-treatment process. The VFA concentration in the digester (R2) effluent was low and generally in the range of 50-100 mg/L. The combination of biogas production and low VFA concentrations in the digester effluent are a good indication of a healthy and stable process.

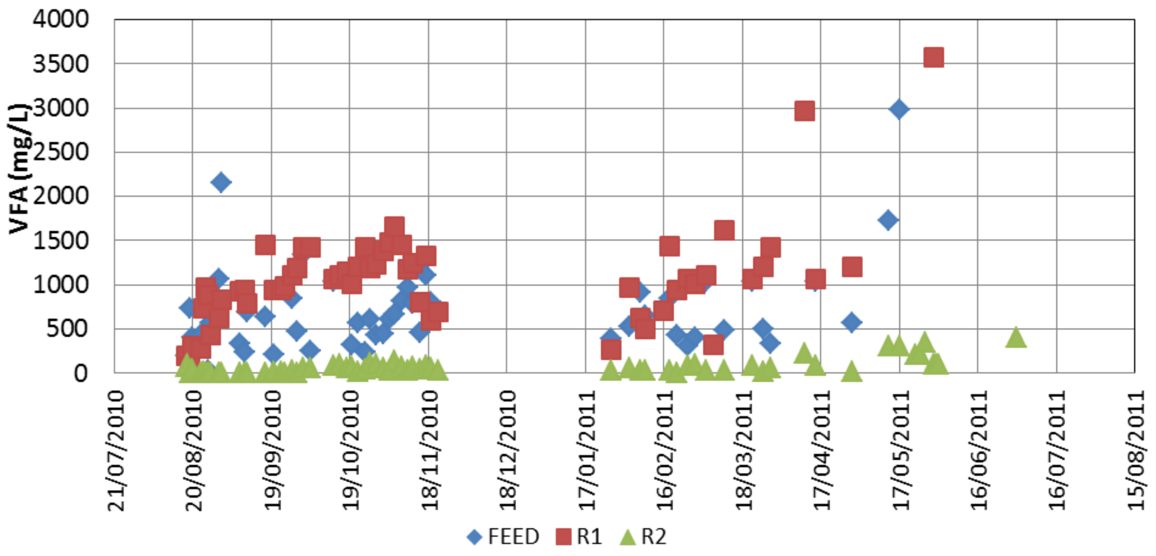

Figure 15: Concentration of volatile fatty acids in the feed material, thermophilic pre-treatment (R1), and digester (R2).

3.5.2 Stage 2: Paunch Solid Waste

At the time of this report, the automated solid feeding system had been installed and the plant commissioned for Stage 2, operation on paunch solid waste. Date for stage 2 is preliminary and will be completed during MLA project A.ENV.0099. Due to blockages and other operational issues, the demonstration plant was operated with an average loading rate of 40 kg volatile solids per day, or 0.5 kg VS/m^3/day. This is approximately 40% of the design loading rate (1 kg VS/m^3/d). The design organic loading rate is conservative and a full scale implementation should be able to operate at an organic loading rate of 2 kg VS/ m^3/day.

The demonstration plant produced biogas at approximately 370 L/kg VS added, the biogas composition is approximately 65% methane and 35% carbon dioxide (traces of H_2S are likely), this corresponds to methane of 240 L/kg VS which is equal to the biochemical methane potential predicted during laboratory tests. The biogas was used to fire an industrial gas water system with no pre-treatment or conditioning. A summary of the organic load, and biogas production is shown in Figure 16.

Preliminary volatile solids destruction is shown in Figure 17 and is above 60% for all calculation methods confirming that the plant is achieving a high level of solids destruction.

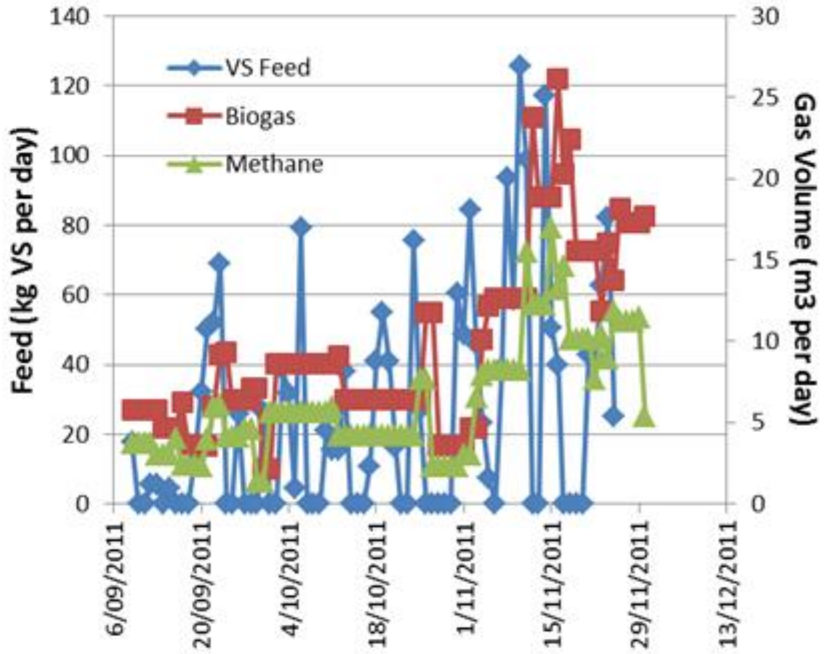

Figure 16: Biosolids Demonstration Plant: Feed Load and Gas Production during Stage 2

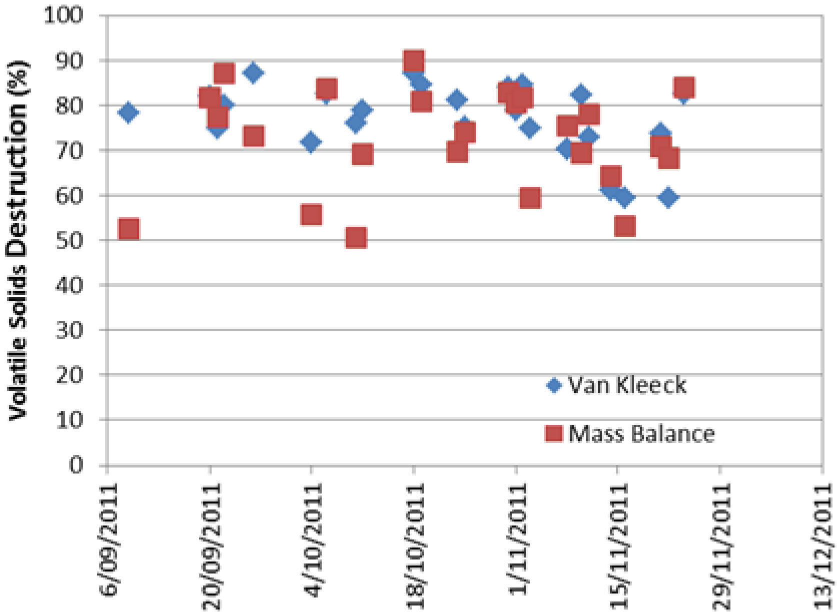

Figure 17: Biosolids Demonstration Plant: Volatile Solids Destruction during Stage 2

3.6 Operational Challenges

3.6.1 Host Site Operations

The host site schedules a full plant maintenance shutdown for 4 weeks each summer (approx 20th Dec to 20th Jan). No feed material is available during the host site maintenance shutdown, therefore the demonstration plant was shut down from mid-December 2010 to late January 2011. The demonstration plant was successfully restarted in January 2011, indicating that the plant is robust enough to handle these process disruptions. The host site also experienced regular plant shutdowns of 1-2 days during 2011. These ongoing process disruptions have a noticeable impact on gas production, however there is no significant effect on the biosolids quality from the demonstration plant as exhibited by low VFA (<100mg/L) in the digester effluent.

3.6.2 Digester Mixing Pump

The demonstration plant was shut down for 2 weeks in June 2011 for maintenance to the digester recirculation pump. The digester recirculation pump was leaking oil due to a faulty seal; therefore the maintenance/shutdown requirements were due to a manufacturing fault and not the result of plant operation.

3.6.3 Gas HWS Failure

Gas volume measurements are performed as the biogas feeds into a hot water system (HWS) used to heat the thermophilic pre-treatment reactor, therefore, when the HWS is offline, biogas is vented to atmosphere and production volumes cannot be measured. The gas HWS was offline for maintenance several times in early 2011 before eventually failing. We are now looking to install a new HWS and modify the gas measurement system to allow us to measure biogas volumes independently.

The gas HWS failure was due to a build-up of carbon deposits on the heat exchanger within the unit. The carbon build up was obscured from visual inspections during initial maintenance checks and eventually lead to a complete failure of the heat exchanger and the gas HWS, shown in Figure 18. Maintenance checks and service by a qualified gas fitter are recommended at intervals of two months to prevent a reoccurrence of this problem.

Figure 18: Gas HWS heat exchanger after failure.

4 Data for Preliminary Cost-Benefit Analysis

4.1 Capital Installation

4.1.1 Stage 1 Capital Costs

Approximate capital expenditure on the stage 1 demonstration plant was $315,000. A breakdown of capital expenses is shown in Table 3. These costs do not include engineering and labour costs of UQ personnel. The cost of the demonstration plant is higher than a full scale equivalent due to experimentation with equipment and process configurations. The cost for a full scale plant can be estimated on the basis of reactor volume. The estimated cost is $1,000 per m^3 for reactor vessels, or $1,500 per m^3 total installed cost with ancillary equipment (e.g. total plant cost). The operating life of the plant is 25 years for key process vessels.

Table 3: Approximate capital expenditure for the Stage 1 demonstration plant

Capital Area	Cost
Foundation	$ 30,095
Process vessels	$ 151,916
Pumps	$ 37,941
Heat Exchange	$ 14,600
Control system	$ 49,550
Piping	$ 32,500
Total	**$ 316,602**

4.1.2 Stage 2 Capital Costs

Approximate capital expenditure to upgrade the demonstration plant to include an automated solids handling system in stage 2 is shown in Table 4. The combined capital cost of stage 1 and stage 2 was approximately $350,000. These costs do not include engineering and labour costs of UQ personnel.

Table 4: Approximate capital expenditure for the Stage 2 demonstration plant

Capital Area	Cost
Solids Feed System	$ 13,800
Process Vessels - Mixing	$ 2,340
Pumps	$ 1,650
Heat Exchange	$ -
Control system/electrics	$ 15,857
Piping	$ 5,000
Total	**$ 38,647**

4.2 Operating Expenditure

4.2.1 Reactor Heating

The pre-treatment reactor and the digester are required to operate at 60°C and 35°C respectively. Under the design hydraulic load conditions (18 day HRT), the heat load on the process is estimated at 0.10-0.15kW per m^3 total reactor volume.

The demonstration plant was heated using a 12kW electric hot water system when no biogas was available. Biogas produced by the demonstration plant was then used to offset the heating requirements. However, ideally, the process would be heated using waste heat from the host plant (e.g. rendering plant). A summary of the heat demand and heating options for the demonstration plant is:

- 12kW electric hot water system – constant supply (290kW.h per day)
- ~50m^3 biogas (~30-35m^3 methane) per day
- Waste heat from rendering plant

4.2.2 Electrical Usage

The primary electrical consumption from the demonstration plant was due to reactor mixing. The pre-treatment reactor was mixed using a 4kW positive displacement pump (50% load). The digester was mixed using a 15kW positive displacement pump (50%) load. A summary of the major units and electrical consumption is shown in Table 10. Total electrical consumption is estimated at ~240 kWh per day which corresponds to ~0.1 kW per m^3 total reactor volume. The demonstration plant mixing system has not been optimised and uses substantially more energy than an optimized full scale system (0.01-0.02 kW per m^3). The electric HWS (max. capacity 10.8kW) is a back-up heat source for the pre-treatment reactor; however the electric HWS is not metered.

Table 5: Typical electrical usage for the demonstration plant

Equipment	Installed capacity	Operating duty	Usage per day
overhead mixing	0.6 kW	100% load 5 hours per day	~3kWh per day
Feed Pump	2.2 kW	90% load 1 hour per day	~2kWh per day
Transfer Pump	2.2 kW	60% load 1.5 hours per day	~2kWh per day
Waste Pump	2.2 kW	60% load 1.5 hours per day	~2kWh per day
R1 mixing	4 kW	60% load 24 hours per day	~58kWh per day
R2 mixing	15 kW	50% load 24 hours per day	~180kWh per day
Electric HWS	10.8 kW	Variable load, not metered	unknown

4.2.3 Water Usage

During Stage 2, the demonstration plant used up to 3 m^3 process water to dilute paunch cake to 3% TS for feed operations. However, in a full scale implementation, where paunch is not screened and dewatered prior to treatment, dilution water would not be required. A small amount of potable or recycled water was used in wash down and cleaning operations, however this was also minimal.

4.2.4 Operator Labour

The demonstration plant had 2 researchers with an onsite presence of approximately 0.25 FTE each (0.5 FTE total). Operator input largely related to clearing blockages in process equipment. The frequency of blockages in the demonstration plant was higher than a full scale plant due to reduced pipe diameters and limitations in equipment availability (e.g. appropriate feed macerator), and an operator requirement of 0.25 FTE should be sufficient. Plastic intestinal plugs and foreign items (e.g. plastic clamps and boning knives) were regularly found and removed from the feed tank. However with the exception of the plastic clamps these items are too large to enter the pipelines and are not considered as major contributing factors in blockages to date. The plastic clamps do contribute to blockages in the process lines; however most blockages to date have been plugs of feed material and occur more frequently when straw like material is present in the feed. The most common location of blockages is within the feed macerator located within the feed tank. Additional blockages have occurred in transfer lines, generally at the bottom of vertical pipe sections. Semi-continuous operation likely contributed to this probably by allow material time to settle between feed events. Therefore the feed macerator required regular cleaning (every 1-2 days) by the operators (frequency would be reduced in a full scale plant) and it is recommended that transfer lines be flushed at the end of the day and/or on the weekends. All other maintenance and cleaning operations are covered by the operator input.

4.2.5 Maintenance Expenses

There have been 3 major maintenance operations since the plant was originally commissioned in August 2010 (all equipment was originally new, for the demonstration plant):

Digester recirculation pump: The digester recirculation pump had a faulty seal between the oil reservoir and the electric motor. The faulty seal was a manufacturing fault, not a result of equipment wear and failure. However the fault was not immediately apparent as the oil initially accumulated in the bottom of the motor, replacement of the faulty seal was ~$1,200.

Feed pump, worn stator: The stator in the feed pump was damaged in November 2011. The failure was the result of a control system failure. Software used to remote access the control computer resulted in the computer freezing during a feed operation. The project team was unable to remote access the plant and were not able to contact staff at the host plant. Therefore the feed pump was run dry for up to 30 mins until project staff arrived on site and the stator was damaged as a result. Pump operating hours were at this time were approximately 400hr and replacement of the damaged stator was ~$1,200.

Gas Hot Water System: The gas hot water system experienced a complete system failure in early 2011. At this time the Gas HWS had processed ~ 1400 m^3 biogas over ~ 450h operation. The primary cause of the failure was a build-up of carbon deposits within the gas HWS. This reduced heat transfer performance resulting in parts of the unit overheating and key internal components were damaged. Investigations indicate that the carbon deposits were due to poor combustion of the biogas. Fluctuations in biogas compositions and the presence of water in the biogas were contributing factors. Initial inspection procedures did not identify the carbon build-up, partly due to the orientation of the heat exchanger within the HWS. Inspection procedures have been updated and in addition, the gas hot water system will now be serviced by a qualified gas fitter at intervals of two months. Replacement cost was ~ $4,000.

5 Summary of Project Outcomes

The project is based on the technology Temperature Phased Anaerobic Digestion (TPAD) and is divided into Sub-project 1: laboratory work, and development of key IP, and Sub-project 2: Pilot-scale demonstration facility. There were 8 formal project research milestones to be completed as part of the initial project. All milestones are now complete.

5.1 Sub-project 1

Bench scale laboratory reactors were constructed and operated to meet the requirements of sub-project 1 (Project Research Milestone 2: Construct and test bench scale digesters (2) and batch evaluation system, Project Research Milestone 3: Analysis of the mechanisms of thermal pre-treatment, Project Research Milestone 4: Evaluation of pathogen destruction). The experimental work in sub-project 1 was based around an engineering approach to operate and model bench scale reactor systems and a molecular approach to study the microbial communities.

In laboratory tests, the TPAD process achieved 54% volatile solids destruction operating on primary sludge and up to 48% volatile solids destruction operating on BNR sludge. These performance characteristics exceeded the benchmarks of 50% and 35% stated in the project milestones. Investigations confirmed that improved hydrolysis rates are the primary mechanism resulting in enhanced performance from thermophilic pre-treatment during TPAD. The project further demonstrated that increased temperature was the primary operating condition contributing to improved hydrolysis rates and determined that pre-treatment at 65°C for 2 days was optimal for process enhancements.

The molecular project examined microorganisms active in the thermal pre-treatment stage of TPAD system, to provide key conceptual insights of the hydrolysis-fermentation step. Molecular identification studies showed that the thermophilic pre-treatment community was highly specialised and dominated by genera Lutispora themophila and Thermotogae. In comparison, the mesophilic pre-treatment communities were highly diverse and less specialised. Analysis of microbial function showed that proteins identified in the thermophilic community had a significantly higher abundance of extracellular solute/ligand binding proteins than mesophilic sludge which are likely important for the enhanced hydrolytic performance of the thermophilic pre-treatment stage.

Evaluation of pathogen destruction was investigated with support from Murdoch University (WA). Results provided by Murdoch University showed that pathogen destruction achieved during the laboratory experiments was not directly linked to pre-treatment temperature as expected. However, the results did confirm strong pathogen destruction was accomplished from the TPAD process.

5.2 Sub-project 2

A demonstration plant based on Temperature Phased Anaerobic Digestion (TPAD) was designed and constructed to meet the milestones of sub-project 2 (Project Research Milestone 5: Sub-project 2 core and coordination activities, Project Research Milestone 6: Planning and Preliminary design, Project Research

Milestone7: Construction and commissioning, Project Research Milestone 8: Operation and optimisation). The demonstration plant consists of a thermophilic pre-treatment vessel (55-60°C, 2-4 days), a mesophilic digestion vessel (35°C, 12-20 days), an industrial water heater (modified to run on biogas), and ancillary process equipment. The pre-treatment vessel (R1) and digester (R2) are cylindrical vessels constructed from 304 stainless steel, capacity and dimensions are approximately 20m^3 (3m diameter, 3m height) and 95m^3 (5m diameter, 4.8m height) for the pre-treatment and digester respectively. The plant occupies a footprint of approximately 10m x 12m.

The demonstration plant was originally commissioned in August 2010 and operated successfully for 1 year to treat wastewater and sludge associated with the generation and handling of paunch solid waste (Stage 1). The demonstration plant was able to treat 5 – 6m^3 wastewater per day producing over 15m^3 of biogas. The biogas composition was typically 63% methane (CH_4) and 37% carbon dioxide (CO_2), this corresponds to 10m^3 of CH_4 per day or ~300 L CH_4 per kg VS added. The combination of biogas production and low VFA concentrations in the digester effluent are a good indication of a healthy and stable process. Biogas has been used to fire an industrial gas hot water system and offset heating requirements of the demonstration plant. However, due to the low concentration of organic material present in paunch wastewater (<1%) biogas production during this first stage of operation was not sufficient to fully offset heating requirements and/or generate excess energy for the host plant. An Open day for Stage 1 of the demonstration plant was held on February 25th 2011 and was attended by UQ, MLA/AMPC, Qld Government representatives, members of the red meat industry from around Australia.

In 2011, the demonstration plant was upgraded with the implementation of an automated solids handling system capable of feeding whole paunch solid waste. This enhanced capacity to assess high-solids feed levels and demonstrate process performance. The demonstration plant has now operated for 3 months stably on a higher solids feed (~2-5% feed), and detailed results can be reported. Solids destruction levels are high, with laboratory tests returning a VS destruction of approximately 65%, and in-reactor performance achieving >60% (based on 3 calculation methods). This indicates that full scale implementation of TPAD would allow every 10 tonnes of solid waste to be reduced to 4 tonnes of organic fertilizer. Biogas production both in the lab and in-reactor are averaging 240 L CH_4/kg VS loaded (1 atm/15°C), this corresponds to 9 MJ energy available to offset energy requirements of treatment or host plant operations.

Overall installed costs of the demonstration plant were $350,000 and costs were approximately 65% process vessels ($1000 per m^3 installed volume), and 35% ancillaries ($500 per m^3 installed volume). Current heat load is 2.4 kWh/m^3/d. Electrical input is very high at approximately 2.4 kWh/m^3/d, however, this could not be optimised due to the size of the demonstration system. Full-scale systems normally operate at 0.1-0.2 kWh/m^3/d. We estimate that ongoing operations would require operator input at 0.25 FTE, including a solids handling system. Based on biogas production yields in the demonstration plant, an organic load of 1.2-1.4 kgCOD/m^3/d is required to meet the energy demand of an optimised demonstration plant. The current demonstration plant will handle feed material concentrated up to 6% solids, and/or reactor loading up to 2 kgCOD/m^3/d. This confirms that the demonstration plant is able to generate excess energy to offset requirements of the host plant.

6 References

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