final report

Project code: A.ENV.0099

Prepared by: Paul Jensen and Damien Batstone

Advanced Water Management Centre
The University of Queensland

Date submitted: September 2012

Date published: Month Year

PUBLISHED BY
Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Solids digestion pilot study at Teys Bros Beenleigh (Extension)

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government and contributions from the Australian Meat Processor Corporation to support the research and development detailed in this publication.

Executive Summary

This is the final design report for the Biosolids TPAD Demonstration plant constructed and operated as part of MLA/AMPC project A.ENV.0099. 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.

The project was based on the technology of 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 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 contains design information on Sub-project 2: Pilot scale demonstration facility, including the demonstration plant and all major process vessels, design of the process monitoring and control system, with electrical/wiring diagrams and basic instructions on how to commission and operate the plant.

Table of Contents

1 Summary of Project Outcomes

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 – 6kL 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 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. 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 kL installed volume), and 35% ancillaries ($500 per kL installed volume). Current heat load is 2.4 kWh/kL/d. Electrical input is very high at approximately 2.4 kWh/kL/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/kL/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/kL/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/kL/d. This confirms that the demonstration plant is able to generate excess energy to offset requirements of the host plant.

Independent NPV based anlysis for TPAD applied to domestic sludge treatment has been conducted by TYR consulting (for Gold Coast City Council), CH2M Hill (for Unity Water), and is currently being assessed by MLA/AMPC for the red meat industry. NPV based costs per wet tonne for large scale domestic units have been placed in the range of $50-$65 per wet tonne. The MLA/AMPC analysis is not yet complete, but is likely to be well below this level due to the lower sensitivity of the material.

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; a full equipment list is included as Appendix A. 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.

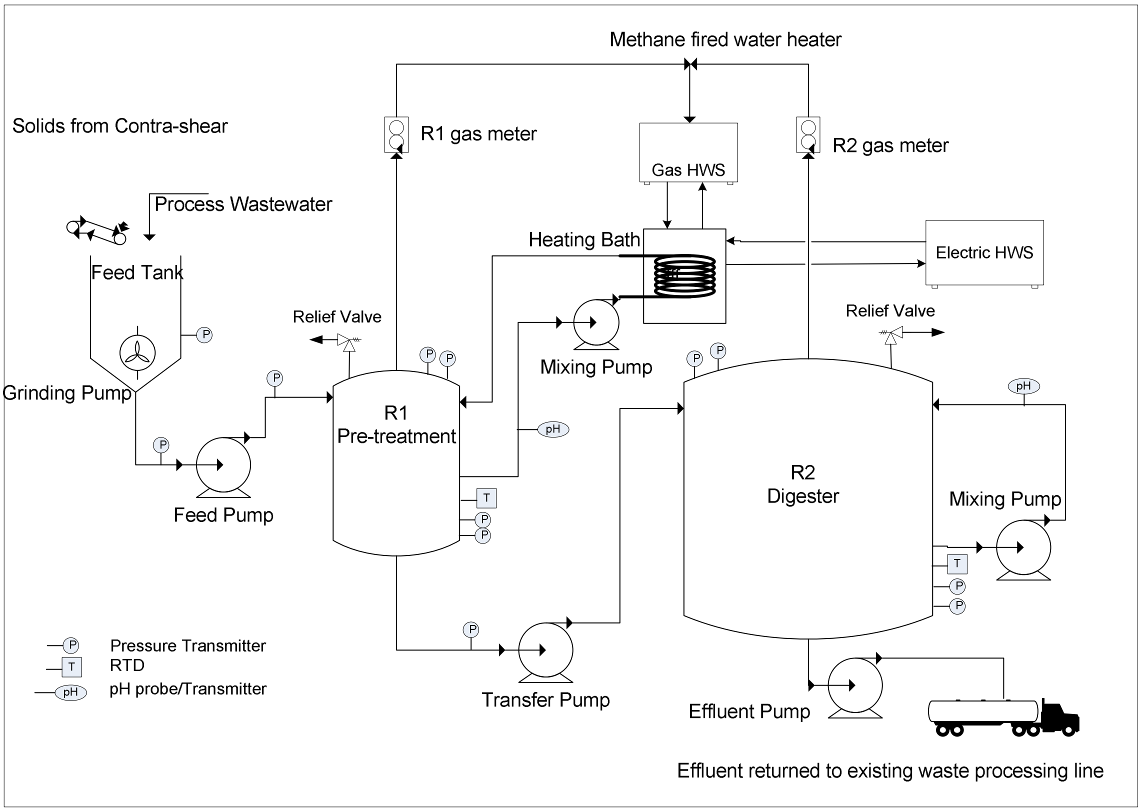


Figure 1. TPAD demonstration plant process flow diagram

The demonstration plant is monitored and controlled using field sensors and a process logic control (PLC) system. The process control system contains 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 Construction

2.2.1 Plant Geography/Foundation

The demonstration plant is 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.

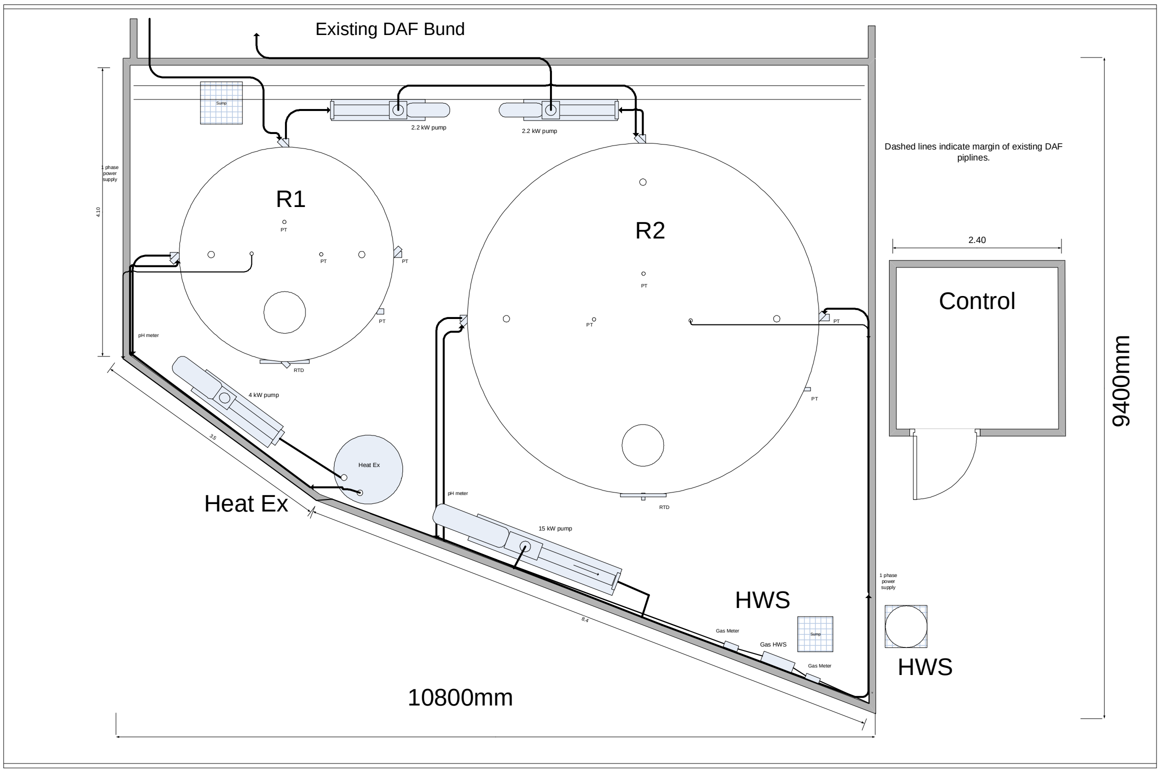


Figure 2: TPAD demonstration Plant Layout and Footprint excluding feed tank.

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.

2.2.2 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 kL (3 m diameter, 3 m height, raked roof). The tank is operated at 10kL providing a retention time of 2 days at a feed rate of 5 kL 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.

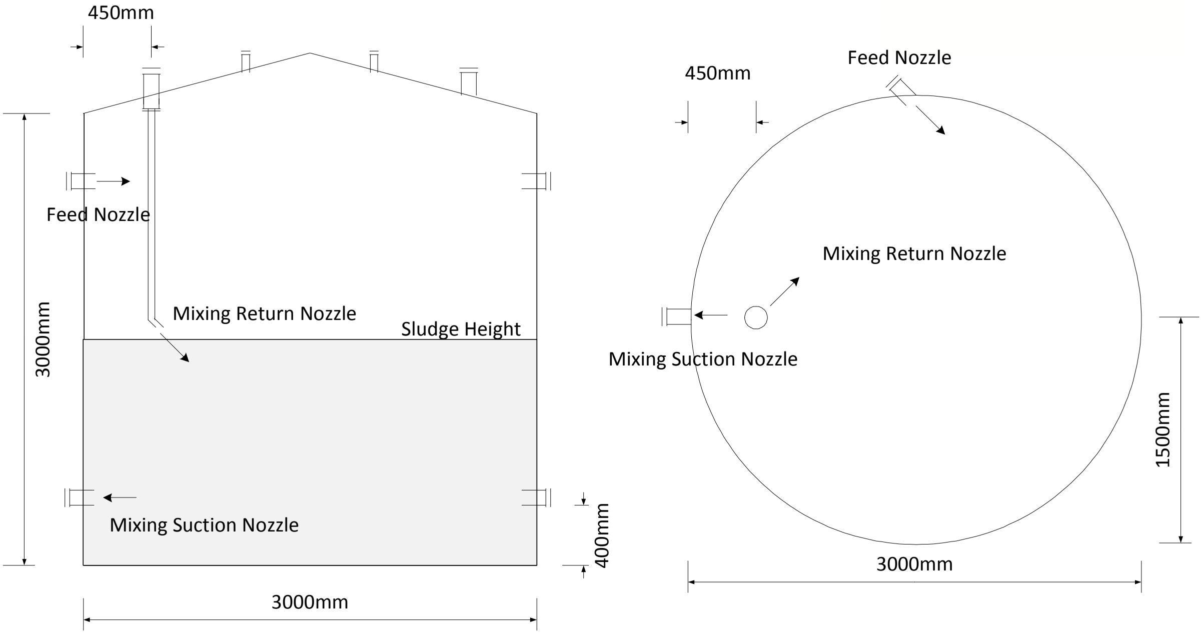


Figure 3: Pre-treatment tank: dimensions, location of feed points, withdrawal points and mixing nozzles

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.

2.2.3 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 kL (5 m diameter, 4.8 m height, raked roof). The tank is designed for operation at 80 kL providing a retention time of 16 days at a feed rate of 5 kL 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 (Metcalf and Eddy 2004).

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.

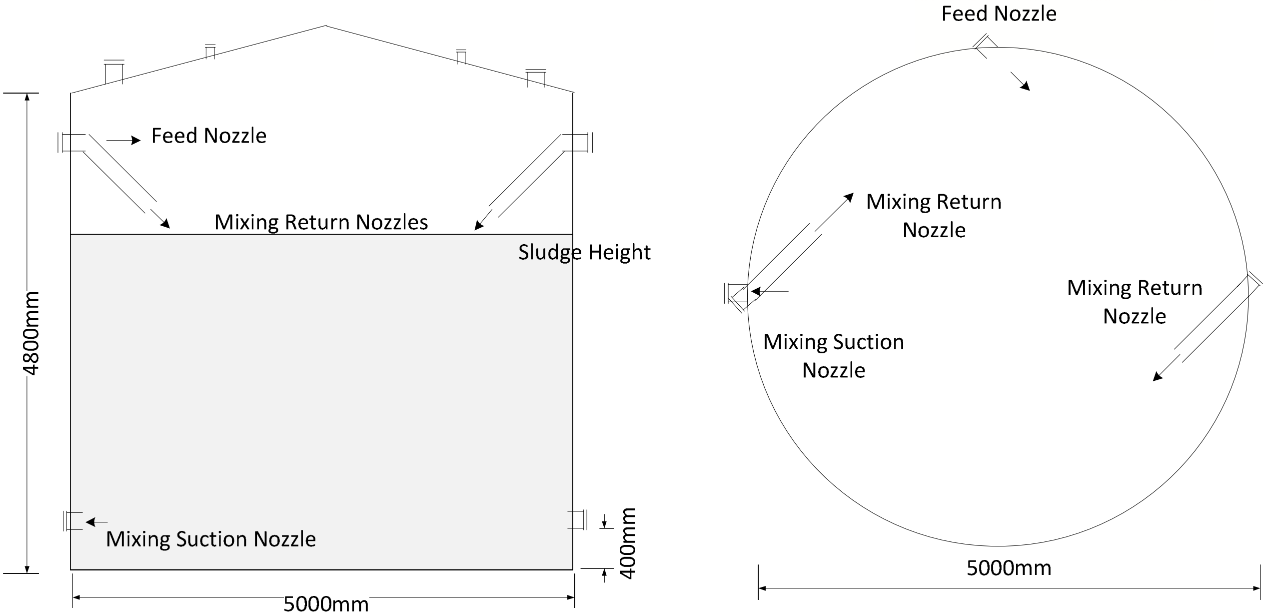


Figure 4: Anaerobic Digester: dimensions, location of feed points, withdrawal points and mixing nozzles

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.

2.2.4 Heat Exchanger

Temperature control in the pre-treatment reactor is achieved using a shell and tube style heat exchanger. The heat exchanger is 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 is 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 is primarily heated using a gas hot water system (GHWS) running on biogas produced by the demonstration plant. An electric hot water system (EHWS) system is 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

2.2.5 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 is 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 2011.

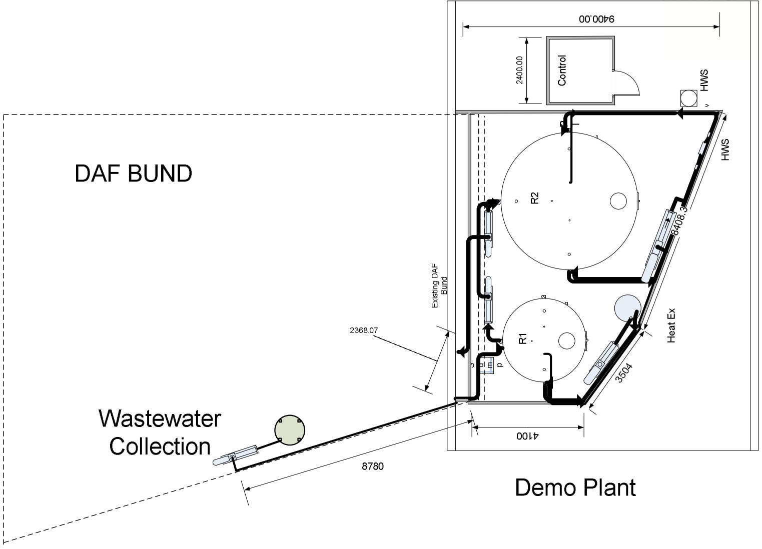


Figure 7: Layout of wastewater handling system within demonstration plant host site in 2011.

2.2.6 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.

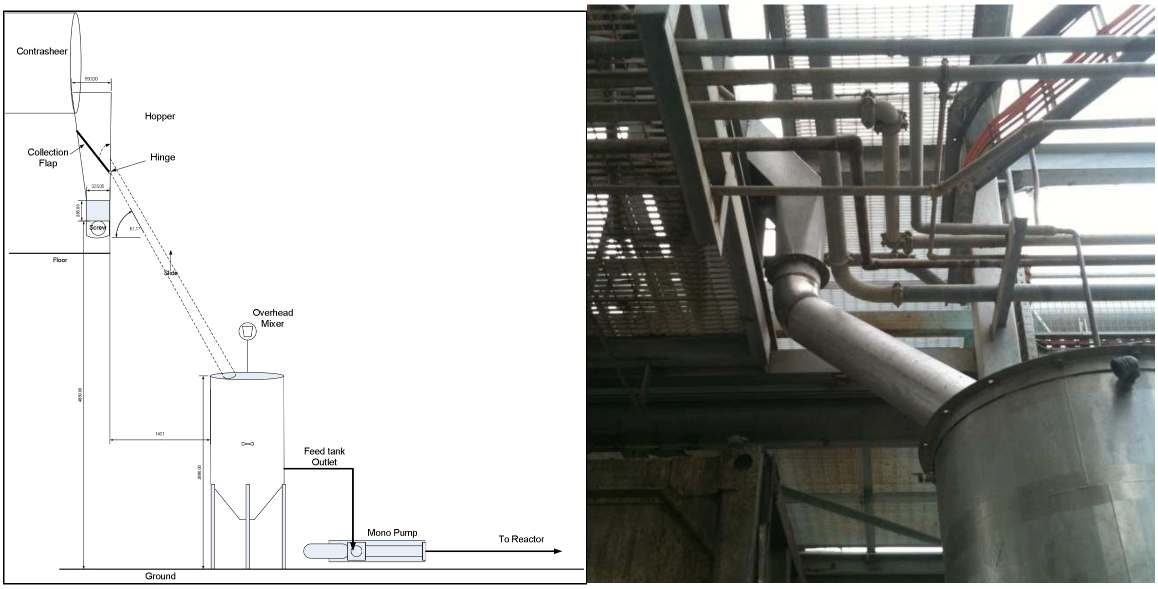


Figure 8: Contrashear and collection chute at demonstration plant host site in 2012

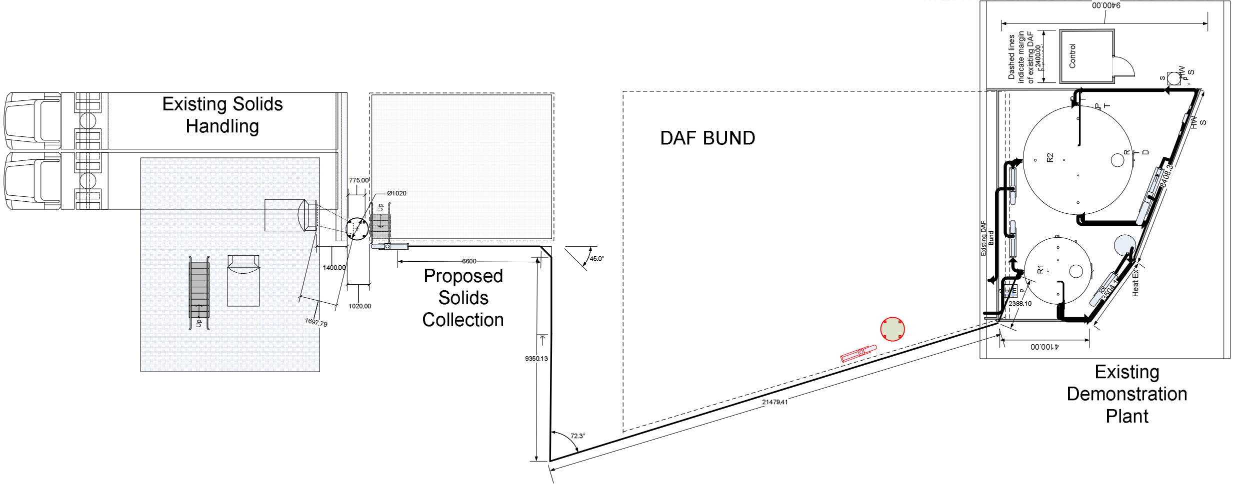


Figure 9: Layout of Solids Handling System within demonstration plant host site in 2011

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.

2.2.7 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 is 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

2.3 Mode of Process Operation

2.3.1 Reactor Feeding Cycle

The demonstration plant host site currently operates on 2 shifts 5 days per week. Therefore during normal operation fresh feed material is available 16 hours per day, 5 days per week. The hydraulic loading rate to the plant is approximately 5 kL per day, under continuous operation this loading rate is not high enough to maintain flow velocity in the feed pipelines high enough to prevent solids settling and blockages. Therefore, due to practical requirements the demonstration plant operates in semi-continuous mode with 10 pulse feed events per day. The use of 10 short feed events per day is designed to mimic a more continuous process that would be the recommended operating mode in a large scale application, however in a smaller application the plant would operate successfully if feed events occurred once per day or less.

Each feed event consists of 3 discrete pump/transfer events. First, a volume of stabilised effluent is wasted from the anaerobic digester (R2), second an equivalent volume of pre-treated wastewater/sludge is transferred from the pre-treatment reactor to the digester, and finally an equivalent volume of feed material is added to the pre-treatment reactor from the feed tank. The feeding cycle is run in a series of discreet events so that power usage at any one time doesn’t exceed the amperage rating of the demonstration plant supply power. It also allows monitoring of the process so that any problems with a particular feed event can be examined with ease. A typical feed event runs for 20 mins with intervals of 90 mins between the start of event.

Currently there are 10 feed events per day at 500 L per event (5 kL total). The total volumetric feed load is designed to maintain the 2 day HRT in the pre-treatment reactor. Variations in this volumetric load may influence how the process operates including stress/overload of the biological communities and should be considered in control/monitoring operations (e.g. large increases in volumetric load may cause stress, washout and eventual failure of the pre-treatment reactor). The organic loading rate may be varied by varying the feed concentrations.

2.3.2 Temperature Control

The thermophilic pre-treatment reactor requires significant energy input to heat incoming feed from room temperature (~20°C) to operating temperature (50-70°C) and compensate for heat loss. Heating is achieved circulating the contents of pre-treatment reactor through the tube side of a shell and tube heat exchanger. The shell side of the heat exchanger contains hot water that is primarily heating using the using biogas generated by the demonstration plant, however an electric HWS is also connected to provide additional heat where biogas production is not sufficient to meet heating requirements.

The design operating temperatures for the anaerobic digester is approximately 35°C, the anaerobic digester receives thermophilic effluent from the pre-treatment reactor at 50-70°C, the heat energy from this transfer of material is sufficient to maintain temperature at the operating set point. Insulation is added or removed from the anaerobic digester to assist with maintaining temperature. This is an effective method of recycling heat from the thermophilic pre-treatment reactor, however it is an indirect method of control; there is no redundancy in the event the feed and transfer processes are not operating. Independent heating for the anaerobic digester is recommended as a redundancy for any future installations.

Note: both reactors require low quality heat (e.g. waste hot water at/or above 50°C is sufficient), currently this is provided by biogas produced by the demonstration plant, however there may be sources of waste heat from operations at the host site (e.g. waste heat from rendering) that are more appropriate for a full scale installation.

2.3.3 Biogas Management

During normal operations, methane rich biogas (60-65% CH_4) is continuously produced in the plant, however the production rates vary due to the semi-continuous feed mode. Currently, biogas is allowed to accumulate in the headspace of each reactor, once the headspace pressure reaches an upper set point (~12 kPa) biogas is released to a modified gas hot water system (GHWS), once the headspace pressure falls to a lower set point (~8 kPa) the biogas release is stopped. The GHWS circulates hot water to the shell side of a basic shell and tube heat exchanger.

While the biogas is currently used to supply heat to the demonstration plant, it could also be added directly to an existing boiler to offset natural gas usage (modifications may be required) and/or used to fire a gas engine to generate electricity.

Biogas quality (composition of CH_4, CO_2, H_2S) and moisture content has been identified as a key issue relating to operation and maintenance of equipment using the gas e.g. sulphides (H_2S) in the biogas lead to increased corrosion, while high moisture content or low methane content in the biogas can result in incomplete combustion, poor operation of the equipment and increased maintenance requirements.

2.3.4 Mixing

Reactor mixing

The pre-treatment reactor (R1) and the main digester (R2) are each constantly mixed using external pump re-circulation. The mixing system was designed based on heuristics and tuned using visual inspections of the sludge behaviour. The reactor turnover rate is currently 45 mins and 100 mins for R1 and R2 respectively. The system has not been optimised or assessed using computational fluid dynamics (CFD). Typical design parameters for anaerobic digester mixing using external pump recirculation are in the range of 0.005- 0.008 kW/m^3 and tank turn over times are approximately 20-30 min (Metcalf and Eddy, 2004). The mixing efficiency of the reactor is determined by the following factors:

- Reactor geometry
- Nozzle type and size
- Physical properties of the sludge (eg. viscosity, temperature, TS).
- Incoming feed properties
- Outgoing waste properties
- Type of mixing system (gas phase, mechanical agitation, pumping)

During operation, there were significant issues with mixing effectiveness resulting from the formation of a solid scum/foam layer on the surface of the reactor vessels. To counteract this, the mixing system return points were changed to a series of nozzles (see Figure 10). The nozzles are designed to increase the velocity of the recirculated fluid with the aim to maintain a circular flow regime within the reactor. The nozzles location and direction is designed to disrupt the solid scum/foam layer. The digester turn over time in R1 is much shorter than R2; this is to counteract the single nozzle design of the R1 mixing system.

Figure 10: **Nozzles used to mix the anaerobic digester pre-installation**

In a full scale installation, nozzle locations should be designed to: 1. Disrupt solid scum/foam layer and 2. Fluidise digested material and grit from the bottom of the tank. Gas phase mixing is an energy efficient option to consider in a full scale installation. However, gas phase mixing may not be sufficient to disrupt the solid scum/foam layer that forms during paunch digestion.

Feed tank mixing

Initially the feed was macerated using a sewage grinding pump. Initial maceration tests showed promising results and that there was some reduction in particle size along with a significant reduction in the agglomeration of particles and a significant improvement in solids pumpability (Figure 11-left). However, long term application of this method was not successful. The macerating unit was not able to handle the fibrous paunch solids without constant maintenance and cleaning. An example of the accumulation of fibrous material around the pump impeller is shown in Figure 11 (middle), this accumulation would lead to pump blockages and damage. An overhead mixer attached to an open impeller is now being used to mix the tank. The overhead configuration requires significantly lower maintenance and consumes significantly less power, the unit has now been working effectively for 4 months (see Figure 11 – right).

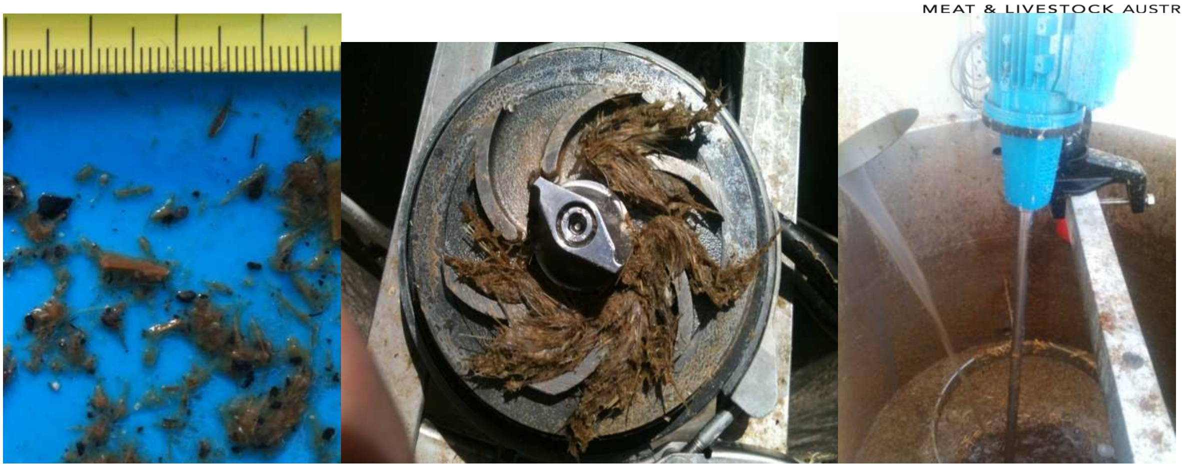


Figure 11: Paunch solids (left), Paunch solids treated using sewage grinding pump for 5 mins (middle), upgraded overhead mixing system (right).

3 Processing Monitoring and Control

Process monitoring and control of the demonstration plant is achieved using 3 mechanisms; field sensors and instruments, a process logic control (PLC) system with human machine interface (HMI) and passive redundancy controls.

3.1 Inputs / Sensors

3.1.1 Temperature

The temperature in each reactor is monitored by a resistance temperature detector (RTD). The RTD 4-20 mA is feed back to the PLC which is read and converted into a temperature reading. This is then logged onto the controlling PC. The temperature in the pre-treatment reactor is used in control loop TR-03.

3.1.2 Gas Pressure

The gas phase pressure in each reactor is monitored using a Druck PTX1400; 4-20 mA pressure transducers. The range of these sensors is -1 to 1.6 bar (g) to facilitate both positive pressure and vacuum measurements. The Pressure in each reactor is measured by two individual sensors running on an intrinsically safe circuit at the top of the reactors. The sensors are duplicated for redundancy.

3.1.3 Tank Level Pressure

The liquid phase pressure in each reactor is monitored using a Druck PTX1400; 4-20 mA pressure transducers located approximately 30cm from the tank bottom. The range of these sensors is 0 to 0.4 bar (g). The liquid head pressure in the tank is determined as the difference between the gas phase sensors and the liquid phase sensors. The tank level/volume is then calculated based on liquid head pressure.

3.1.4 Pipe Pressure

Genspec GS4200; 4-20mA; 0-10 bar (g) pressure transducers are located in several pipelines as a diagnostic tool for detecting blockages. Detecting blockages is critical to prevent pipeline damage and pump damage.

3.1.5 pH

The pH of each reactor is monitored via (Signet 327501; 4-20mA) pH Transducers. The pH is a stability and performance indicator for each reactor and is logged through the PLC. The pH is not used in any control function. In a full scale implementation, pH control may be implemented by connecting a pH senor to an acid/alkaline dosing pump.

3.1.6 Electrical Current

The electrical current to the mixing pump is monitored to the feed tank mixing pump, this is a feedback sensor to confirm if the mixer is operating correctly or indicate failure.

3.1.7 Float Switch

A float switch is used in the feed tank to indicate the tank volume has reached maximum capacity and to stop a feed preparation event.

3.1.8 Position Reed Switches

Reed switches are used on the pneumatic ram which activates the collection chute, these are feedback sensors to confirm if the collection chute is in the correct control position or indicate failure.

3.1.9 Feedback signal from pumps

Mono 3-phase pumps have a feedback system to the PLC to confirm correction operation or indicate failure. Feedback signals are from all the five pumps and used in multiple control loops for mixing and feeding.

3.2 Process Control Loops

3.2.1 Solid Feed System

Control operations for the solid feed system including each control variable (e.g. the set point) and the manipulated variable are shown in Table 3.

Table 3: A summary of all the associated control loops for the solids feeding system

Control Loops Feed System	P&ID	Controlled Variable	Manipulated Variable	Detection Sensor	Justification
Solid addition (SFS-01)	PID-SFS	Solids Added	Chute open time	Feed Tank Pressure Transducer	Control feed (TS) going to the reactor
Mixing Ratio (SFS-02)	PID-SFS	Total solids	Water volume added	Feed Tank Pressure Transducer	Controls solids percentage for feed
Tank Level (SFS-03)	PID-SFS	Tank pressure / Volume	Number of feed prep cycles	Feed Tank Pressure Transducer	Ensures full feed tank for feeding cycle
Chute position (SFS-04)	PID-SFS	Open / Closed	Pneumatic valve	Reed Sensor	Detects correct operation of feed prep cycle
Water time out (SFS-05)	PID-SFS	Water addition	Tank Pressure / Volume	Feed Tank Pressure Transducer	Detects system failure
Mixing (SFS-06)	PID-SFS	Mixer On / Off	Current to motor	Current Sensor	Detects operation of mixing pump
Pipe blockage detection inlet (SFS-07)	PID-SFS	Feed Pump On / Off	Current to Motor	Feed line Suction Pressure	Detects system failure
Pipe blockage detection outlet (SFS-08)	PID-SFS	Feed Pump On / Off	Current to Motor	Feed line Discharge Pressure	Detects system failure
Tank over fill (SFS-09)	PID-SFS	Stop feeding / Feed prep	Alarm	Pressure Transducer	Detects system failure

The feed preparation loop is used to control the concentration of feed material transferred to the pre-treatment reactor. This control loop is critical as a high solids concentration may cause pipeline blockages and process disruptions. Solids concentration is manipulated by measuring the volume of dewatered solids added to the feed tank and adding process water to dilute the solids based on a ratio set point. A ratio of 2 process water to 1 dewatered solids is a typical set point.

There are several feedback control loops attached to the feed preparation cycle of failure to identify abnormal process operations and shut down feed preparation and process feed events.

The Feed Tank Level may exceed the maximum level set point, this may be due to over-collection of feed solids (e.g. due to upstream process characteristics, or failure of feed collection chute), or failure of the process dilution water process. To stop the system and prevent uncontrolled operation a float sensor is attached at the top of the tank to indicate when the tank is completely full. This sensor and will trip a level

2 alarm through control loop SFS-09. A level 2 alarm will shut-down feed operations, but allow the pre-treatment reactor and anaerobic digester to operate as per normal.

Chute failure may prevent the normal opening or closing of the solids collection chute, and this would affect the ability to collect solids or control solids collection. To detect this failure the chute position sensor detects the position of the air ram. The physical position is compared to the logical position and triggers a level 2 alarm through a feedback loop SFS-04 if they are mismatched.

A solenoid valve is used to control the flow of process water used for dilution. The solenoid valve can be subject to blockages due to particulate matter in the water. Water addition is time limited, such that if there is no flow of water the solenoid will switch off and a level 2 alarm is triggered. In the event the value fails open, feed tank will over fill and an alarm will trigger through control loop SFS-05.

Materials handling properties of the solid feed are quite difficult and present a high risk of blockage and/or seizure or the feed tank mixing system If the mixing system is not operating, there is a high risk or blockages in the feed transfer lines, therefore, a current detection module was place on the power line to allow the PLC to know if the mixer is performing as per program. Control loop SFS-06 will trigger a level 2 alarm if there is a mismatch between program operation and actual operation.

Pressure transmitters are located in the feed transfer lines to detect blockage due to the presence of high solids or foreign objects. If a vacuum is detected on the suction side of a pump or if pressure on the discharge side exceeds a programmed threshold, a level 2 alarm is triggered.

3.2.2 Pre-treatment Reactor (R1)

Control operations for the thermophilic pre-treatment reactor including each control variable (e.g. the set point) and the manipulated variable are shown in Table 5.

Table 4: A summary of all the associated control loops for the Thermophilic Reactor (R1)

Control Loops Thermophilic Reactor	P&ID	Controlled Variable	Manipulated Variable	Detection Sensor	Justification
Feeding Pump (TR-01)	PID-TR	Pump on/off	Current to pump	Pump feed back signal Logic	Pump protection
Reactor Level / Pressure Liquid Phase (TR-02)	PID-TR	Reactor Volume	Pump Duty	Dual Pressure Transducer Liquid phase	Feed logic cycle and manual user interface.
Temperature (TR-03)	PID-TR	Pump to EHWS	Reactor Temperature	RTD	Maintain temperature for thermophilic hydrolysis
Reactor Pressure Gas Phase (TR-04)	PID-TR	Reactor Pressure	Pump to GHWS	Dual Pressure Transducer Gas phase	Controls Reactor Headspace Pressure
Mixing (TR-05)	PID-TR	Mixing rate	Current to pump	Pump Feed back	Manual control of mixing rate
Gas Production (TR-06)	PID-TR	N/C	N/C	Gas meter / Sender	Gas Production monitored for long term performance analysis
pH (TR-07)	PID-TR	N/C	N/C	pH Transducer	pH is monitored for long term performance and stability
Alarm no mixing (TR-08)	PID-TR	Pump on/off	Current to pump	Pump feedback signal	Pump Protection
Alarm liquid phase mismatch (TR-09)	PID-TR	Logic alarm	Liquid phase pressure transducer	Dual Pressure transducer	Validate transducer reading
Alarm Gas mismatch (TR-10)	PID-TR	Logic alarm	Gas phase pressure transducer	Dual Pressure transducer	Validate transducer reading
Alarm Volume (TR-11)	PID-TR	Logic alarm	Liquid phase pressure transducer	Dual Pressure transducer	Reactor breech / overfill detection protection of equipment

The pre-treatment reactor was designed to operate at thermophilic temperatures between 50-70°C, this was to allow testing of mildly thermophilic operation and highly thermophilic operation at various stages of the project. However, during an operating period the temperature will be more tightly controlled to maintain the microbial population and activity of the culture within the reactor, (e.g. maintained within 55-60^{o}C). Due to heat loss and disturbances through feeding the temperature is actively controlled.

The Electric hot water system (EHWS) is a back-up system for when Gas hot water system (GHWS) is unable to provide sufficient heat energy. It is required in times of low gas production or during start-up. It is activated by the temperature of R1 dropping below 55^{o}C and deactivated by the temperature rising above 60^{o}C.

The GHWS is used to recover energy from biogas produced in by the demonstration plant. Its two primary functions are to regulate gas pressure in the reactor headspace and to produce heat energy required by the reactors. The reactors convert the feed into biogas, approximately 60% methane and 30% Carbon Dioxide, as the feed is degraded and stabilised, the gas pressure inside the reactor will increase, the gas must be harvested and used to prevent a failure of the reactors. The pressure in both reactors is maintained by releasing the biogas to the GHWS. The Reactors are run at a positive pressure range between 8 kPa to 10 kPa. When the gas pressure in either reactor reaches the upper set-point the control loop TR-04 initiates the gas hot water pump, the movement of water through the GHWS activates the gas flow to the GHWS. The control loops for the two reactors are separate however they manipulate the same output (ie. the GHWS). Thus the pressure for either reactor is dependent on its own pressure and that of the other reactor. This means, for example, if R2 is producing an excess of gas in comparison to the R1, the pressure of the R1 reactor will drop below its defined minimum set point.

The volume of the reactors is determined by the required hydraulic retention time (HRT) within each reactor. The design of the demonstration plant is to have a HRT in R1 of 2 days and a HRT in R2 of 16 days. With a working volume of 10kL and 80kL for R1 and R2 respectively, we require a feeding volume of 5kL per day. The feeding is divided up into 10 feeds per day each of 500L. This can be modified, for example a volume of 625 L could be fed 8 times a day. The modification to the feeding volumes can be performed on the control computer in the HMI set up information. Additionally extra material can be added or removed in manual mode from the reactors.

The automatic feed events are coordinated on a time bases and pump duty. The feed event requires a calibration curve for the pumps.

As each pump is turned on the required information in the setup file is accessed. The program then checks the amount that needs to be fed with the volume that is actually in the tank, this will prevent dry running of the pump if there is not enough feed. The program then calculates a required time for the pump to be on, based on the variable speed drive (VSD) output and the pump calibration curve.

If the calibration curve changes over time then the volume pumped will change and this will change the volume over time. Alternatively if a blockage occurs in the feed line between the suction pressure transducers and the discharge pressure transducer the PLC will not pick this as an alarm state and the feeding will continue, however, the feed will not get to R1. This is an acute problem such that the volume of R1 could be halved in one day. To prevent this, a high and low level alarm is installed on each reactor. The alarm has a dual purpose, one as in the example above, the other is for a pumping / pipe work failure where the reactor contents is lost through structural failure of equipment. For this reason the alarm is a level 1 alarm and will cease all pumping activity in the plant.

The mixing control in R1 has a control loop that detects if the pump is on or off however the performance is not controlled. There is a feedback signal from the mono pumps, if a pump is inactive when is should be running then the PLC will alarm a level 1 alarm for control loop TR-08 (mixing pump). These are in place to prevent pump damage should they be blocked and not able to turn. The mixing needs to be maintained to prevent floating and/or settling accumulation of solids within the reactor. If this is not achieved then the reactor will build up solids and result in eventual reactor failure. To check the mixing of the reactor a total solids measurement should be performed on the influent and effluent of each reactor. Additionally the reactors should be opened and inspected occasionally.

The pH is a variable that is also not controlled but is measured and recorded through control loop TR-07, for signs of reactor distress.

3.2.3 Anaerobic Digester (R2)

Control operations for the anaerobic digester (R2) including each control variable (e.g. the set point) and the manipulated variable are shown in Table 5.

The anaerobic digester does not have active temperature control. The volume is controlled by the user controlled pre-programmed feed cycle, it is actuated by the transfer pump and the waste pump. The heat input is controlled by the mass transfer from the thermophilic reactor. The heat loss is controlled by the thermal insulation around the reactor. There are several active safety control loops that are in effect that are equivalent to the systems in R1 previously described.

Table 5: A summary of all the associated control loops for the Anaerobic Digestion (R2)

Control Loops Anaerobic Digester	P&ID	Controlled Variable	Manipulated Variable	Detection Sensor	Justification
Transfer pump (MR-01)	PID-MR	Pump on/off	Current to pump	Pump feed back signal	Pump Protection
Reactor Level / Pressure Liquid Phase(MR-02)	PID-MR	Reactor Volume	Pump Duty	Dual Pressure Transducer Liquid phase	Feed logic cycle and manual user interface.
Temperature (MR-03)	PID-MR	N/C	N/C	RTD	Temperature is maintained by Mass transfer and heat loss
Reactor Pressure Gas Phase (MR-04)	PID-MR	Reactor Pressure	Pump to GHWS	Dual Pressure Transducer Gas phase	Controls Reactor Headspace Pressure
Mixing (MR-05)	PID-MR	Mixing rate	Current to pump	Pump Feed back	Manual control of mixing rate
Gas Production (MR-06)	PID-MR	N/C	N/C	Gas meter / Sender	Gas Production monitored for performance analysis
pH (MR-07)	PID-MR	N/C	N/C	pH Transducer	pH is monitored for performance and stability
Waste Pump (MR-08)	PID-MR	Reactor Volume	Pump Duty	Logic	Waste reactor digestate
Alarm no mixing (MR-09)	PID-MR	Logic pump on/off	Current to pump	Pump feed back signal	Pump Protection
Alarm liquid mismatch (MR-10)	PID-MR	Logic alarm	Liquid pressure	Dual Pressure transducer	Validate transducer reading
Alarm Gas mismatch (MR-11)	PID-MR	Logic alarm	Gas phase pressure transducer	Dual Pressure transducer	Validate transducer reading
Alarm Volume (MR-12)	PID-MR	Logic alarm	Liquid Pressure	Dual Pressure transducer	Reactor breech / overfill detection

3.3 Passive Control/System Redundancy

3.3.1 Pressure relief

Each reactor is fitted with a U-Tube water lock attached to the headspace. The manometer is a passive safety precaution such that if the headspace pressure increases beyond the liquid head pressure in the U-Tube (approximately 15 kPa) the water lock will cease to be effective and gas will escape through the U-tube. Similarly, if the headspace comes under vacuum beyond the liquid head pressure in the U-Tube (approximately 15 kPa) gas will be drawn from the surrounding environment into the reactor and prevent implosion of the vessel. In addition to the U-Tube water lock, the reactors are fitted with passive spring loaded pressure relief valves that activate at approximately 20kPa.

3.3.2 Bund

The demonstration plant is surrounded by a 1 m concrete bund. The bund is designed to hold the contents of the reactors should catastrophic pump / pipe failures occur. The bund volume will retain the total operational contents of the largest reactor.

3.3.3 Intrinsically Safety for Equipment in Hazardous Zones

All equipment located in hazardous zones (e.g. within 5 m radius of safety relief valves) must be designated and certified intrinsically safe. This applies to the pressure sensors on the top of both reactors. The circuits for these are run on a separate earth line back to the PLC. Details of the hazardous zones, intrinsic safe circuits and equipment are included in the Hazardous Area Dossier (Appendix D). This is a legislative requirement in Queensland and must be considered in any modifications or design requirements.

3.3.4 Duplicate Sensors

The pressure readings are duplicated in the reactors for the case of a pressure transducer failure. If a mismatch occurs then a level 1 alarm will be activated and the plant will go into standby mode where only process variables are monitored.

4 Start-up and Operation Manual

4.1 Full Commissioning and Start-up Strategy

Commissioning the demonstration plant, or start up after an extended shutdown greater than 2 months:

- A check of all the systems and pipe work and reactors needs to be performed.
- The pump calibrations need to be assessed.
- Check all sensors
- Check all valves are in correct positions
- The reactors should be initially loaded with seed material and a portion of substrate (seed material 50% reactor volume is recommended, 10% reactor volume is minimum).
- Seed material to be active anaerobic sludge (e.g. anaerobic lagoon sludge)
- It is important to minimize exposure to oxygen during transfer.
- After initial filling heat the reactors to design temperature and begin continuous operation at 10% organic load. Organic load may then increase progressively to full load over a period of 60 days.
- The stability of the reactors should be closely monitored during this establishment period. If Soluble COD in the anaerobic digester effluent reaches or exceeds 1g/L this may indicate the process is under stress, reduce organic load for several days and slow rate of increase.

4.2 Start-up – From Short Period of Inactivity

Re-starting the plant after a maintenance shutdown event or a period of inactivity greater than 1 week but less than 1 month:

- Check reactors for leaks
- Check all sensors
- Check all valves are in correct positions
- After initial filling heat the reactors to design temperature and begin continuous operation at 50% organic load. Organic load may then increase progressively to full load over a period of 30 days.
- The stability of the reactors should be closely monitored during this establishment period. If Soluble COD in the anaerobic digester effluent reaches or exceeds 1g/L this may indicate the process is under stress, reduce organic load for several days and slow rate of increase.

4.3 Operating Manual

The physical operation of the demonstration plant is relatively straight forward if the plant is operating at a steady state conditions and everything is working as it should. The basics of the plant operation can be completed from the control room as the control system is centralised with all inputs and output coming back to a central PLC.

All manual valves will need to be set at the valve and should be in the correct open / closed positions. Table 6 is a list of valves and standard operating positions at start up. Location of the valves in the P&ID drawings is shown in Appendix C.

Table 6: Table of operational valve positions

Correct Valve position for normal operation			
PID VALVE	Open	Closed	Description
V-1	-	-	Automated, Solenoid valve for Process water, located HRS of Contrashear. Can be manually overridden by software bit O:0/8 or activation by contact in junction box opposite Contrashear.
V-2	-	-	Automated, Solenoid driven pneumatic valve, located RHS of Contrashear. Can be manually overridden by software bit O:0/9 or activation by contact in junction box opposite Contrashear.
V-3	1	0	Manual feed tank isolation 2” ball valve
V-4	0	1	Sample and Cleaning valve 1” Ball Valve post feed tank
V-5	0	1	Sample and Cleaning valve 1” Ball Valve Pre Thermophilic reactor
V-6	1	0	3” Ball valve for Thermophilic isolation from the feed line
V-7	0	1	Sample and Cleaning valve 1” Ball Valve thermophilic recirculation line
V-8	1	0	2” Ball valve for thermophilic reactor isolation from the recirculation pump
V-9	1	0	2” Ball valve for thermophilic reactor isolation from the recirculation pump
V-10	1	0	3” Ball valve located at the base of thermophilic reactor for isolation from the transfer pump
V-11	0	1	Sample and Cleaning valve 1” Ball Valve post thermophilic reactor
V-12	0	1	Condensate from thermophilic reactor gas trap
V-13	0	1	Gas sampling valve
V-14	1	0	GHWS Isolation valve
V-15	1	0	3” Ball valve located at the Top of anaerobic digester for isolation from the transfer pump
V-16	1	0	4” Ball valve located at the bottom of anaerobic digester for isolation from the recirculation pump
V-17	0	1	Sample and Cleaning valve 1” Ball Valve anaerobic digester recirculation line
V-18	1	0	3” Ball valve located at the Top of anaerobic digester for isolation from the recirculation line
V-19	1	0	3” Ball valve located at the Top of anaerobic digester for isolation from the recirculation line
V-20	0	1	Sample and Cleaning valve 1” Ball Valve anaerobic digester recirculation line
V-21	0	1	Condensate from pre-treatment reactor gas trap
V-22	0	1	Gas sampling valve
V-23	1	0	GHWS Isolation valve
V-24	1	0	3” Ball valve located at the Bottom of anaerobic digester for isolation from the waste line
V-25	0	1	Sample and Cleaning 1” Ball Valve pre waste pump
V-26	0	1	Sample and Cleaning 1” Ball Valve post waste pump
V-27	0	1	Pressure relief valve top of anaerobic digester
V-28	0	1	Pressure relief valve top of pre-treatment reactor
	1		Gas valves on top of anaerobic digester for isolation
	1		Gas valves on top of pre-treatment reactor for isolation
		1	Feed tank bottom valve for cleaning

4.3.1 Operation of the HMI Software

There are five screens to the human machine interface (HMI). The HMI can be navigated by use of a mouse pointer. The different screens can be accessed by the five tabs along the top of the screen:

- Overview
- Setup
- Gas
- Temp/pH
- Volume / Pressure

The first two screens, Overview and setup, are for system status and manual setting of parameters for automatic operation. The final three screens are charts and data of the operating parameters history.

Overview Screen

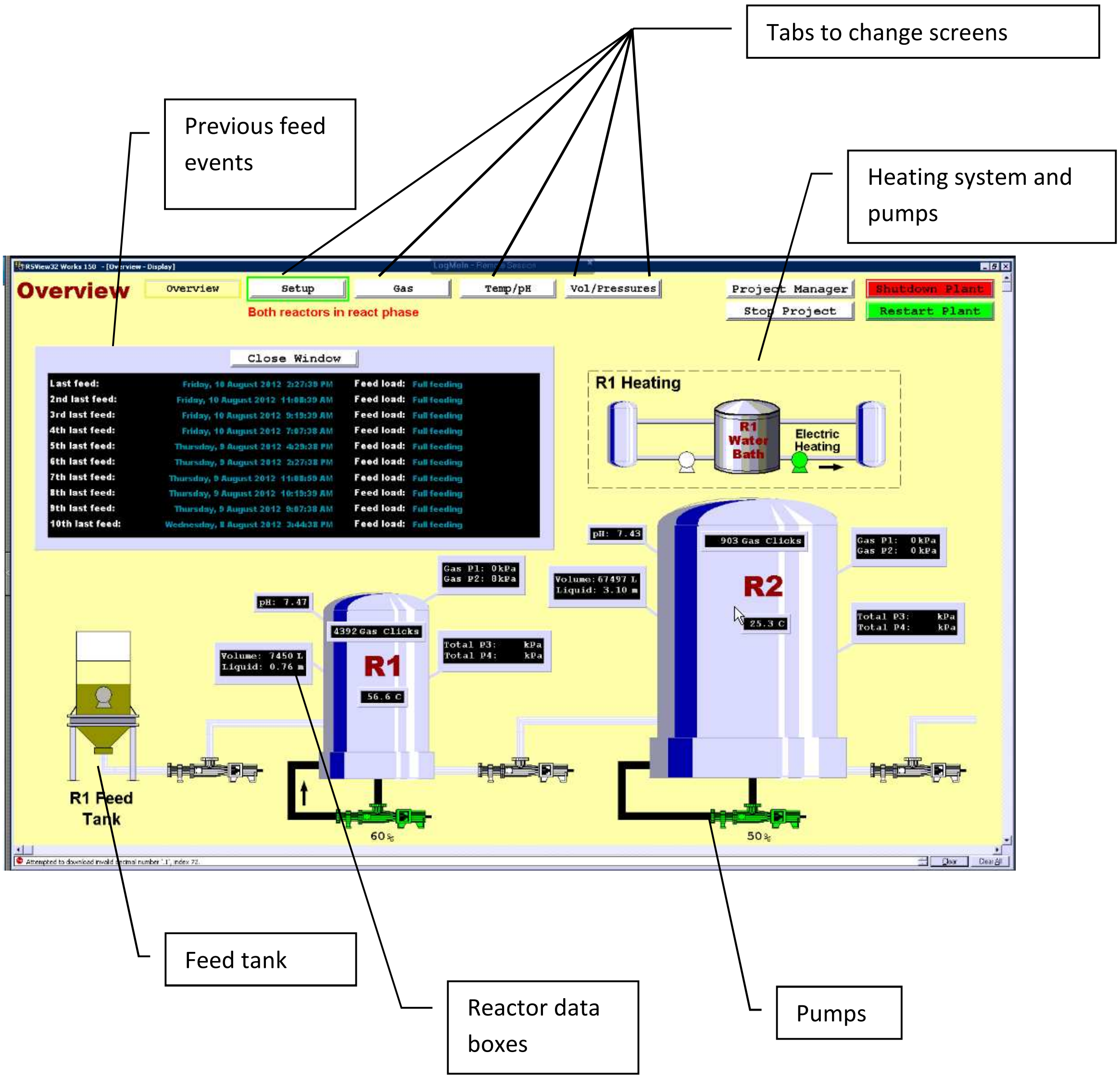
The overview screen gives a diagrammatical representation of the plant with all the pumps, reactors and feed tank. When a unit is in operation it will flash green. During normal operation and between feed cycles only the mixing pumps for the Thermophilic and Mesophilic reactors will be flashing. The Backup electric hot water pump and / or the gas hot water pump may also be active during this time depending on the heating requirements.

During a Feeding cycle each of the other pumps will be activated. The waste pump will be on first then the transfer pump and then the feed pump. The mixing system for the feed tank will also be active before the feed pump is activated.

During the feed preparation above the feed tank the different activities of the cycle will be displayed “chute open”, “Water addition”.

Other features of the overview screen include a display of the prior 10 feeds, time, date and amount. The pumps can all be manually operated from this screen by double clicking on the icon and switching the pumps to manual. All the speeds of the pumps can also be changed through double clicking the icon and changing the speed either in automatic or manual modes.

Additionally if there are alarms active, the alarm and severity of the alarm will be displayed in the top right hand corner of the screen flashing red.



Both reactors in react phase

Last feed:	Friday, 10 August 2012 2:27:39 PM	Feed load:	Full feeding
2nd last feed:	Friday, 10 August 2012 11:08:39 AM	Feed load:	Full feeding
3rd last feed:	Friday, 10 August 2012 9:19:39 AM	Feed load:	Full feeding
4th last feed:	Friday, 10 August 2012 7:07:38 AM	Feed load:	Full feeding
5th last feed:	Thursday, 9 August 2012 4:29:38 PM	Feed load:	Full feeding
6th last feed:	Thursday, 9 August 2012 2:27:38 PM	Feed load:	Full feeding
7th last feed:	Thursday, 9 August 2012 11:08:59 AM	Feed load:	Full feeding
8th last feed:	Thursday, 9 August 2012 10:19:39 AM	Feed load:	Full feeding
9th last feed:	Thursday, 9 August 2012 9:07:38 AM	Feed load:	Full feeding
10th last feed:	Wednesday, 8 August 2012 3:44:38 PM	Feed load:	Full feeding

pH: 7.47
Volume: 7450 L
Liquid: 0.76 m
4392 Gas Clicks
56.6 C
Gas P1: 0kPa
Gas P2: 0kPa
Total P3: kPa
Total P4: kPa

pH: 7.43
Volume: 67497 L
Liquid: 3.10 m
903 Gas Clicks
25.3 C
Gas P1: 0kPa
Gas P2: 0kPa
Total P3: kPa
Total P4: kPa

Figure 12 Overview screen of the HMI

Set-up screen

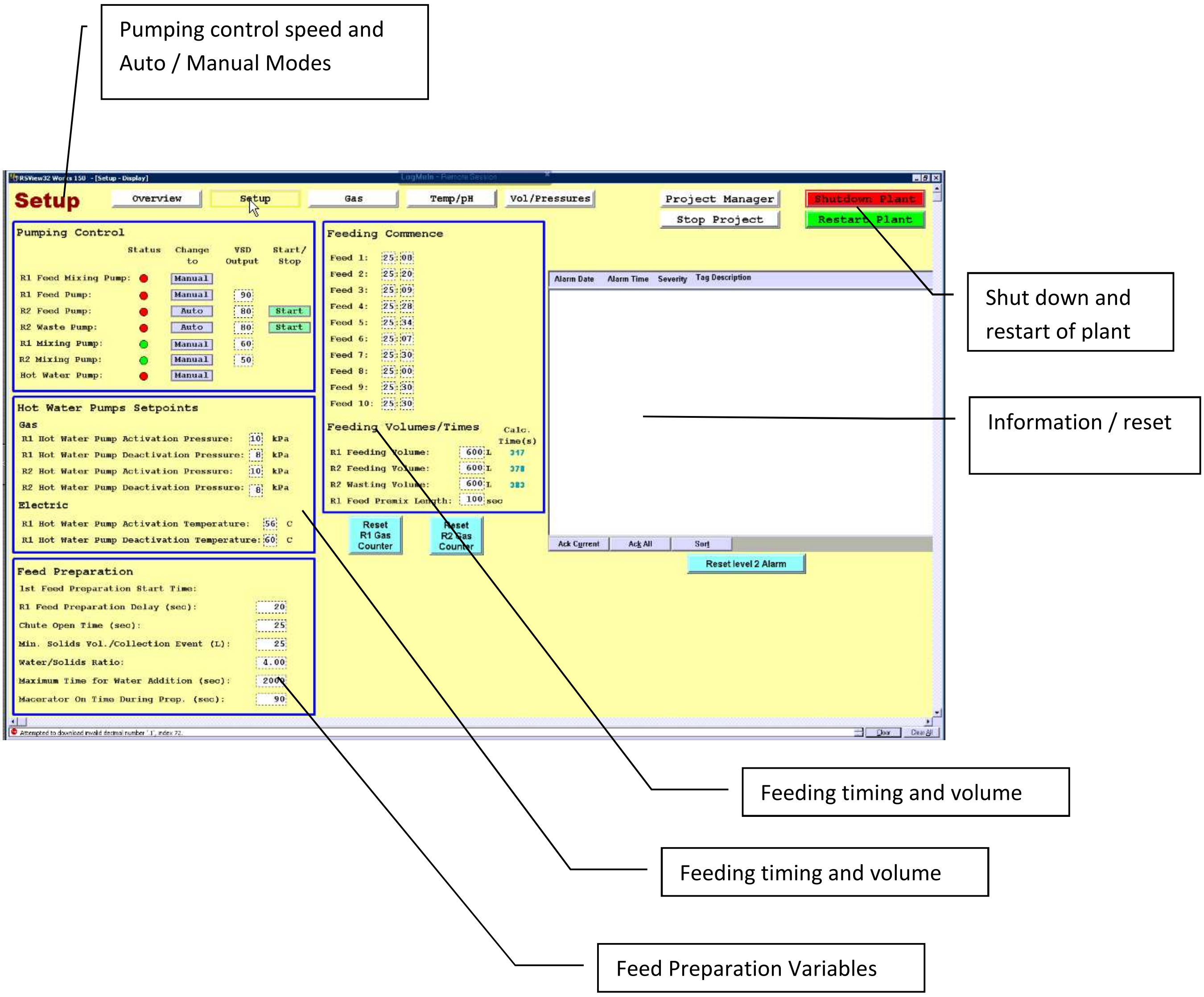
The setup screen allows entry of the operational parameters of the plant. The screen is divided up into 5 main sections. The top left corner allows the user to designate the pump speed and the mode of the pump from automatic to manual operations.

The middle left screen allows control for the pressure that the GHWS is activated; this in turn dictates the operating pressure within the reactor. Also in this box is the set point temperature for the back-up EHWS this ensures that R1 temperature is maintained within the thermophilic set point.

The bottom left box allows manipulation of the feed preparation controls, here the solids ratio can be controlled how long the chute is open for and how long the feed tank is mixed for. The water time out control is also entered here.

The centre box controls when the feed events occur and how many feed events will happen on any one day. The volume of each individual section of the feed event may also be controlled.

The box on the right is an information box. Information about alarms is displayed here. When a level 2 alarm is active the message will appear, the message will need to be acknowledged and then reset once the physical problem is solved.



Pumping Control

	Status	Change to	VSD Output	Start/ Stop
R1 Feed Mixing Pump:	🔴	Manual		
R1 Feed Pump:	🔴	Manual	90	
R2 Feed Pump:	🔴	Auto	80	Start
R2 Waste Pump:	🔴	Auto	80	Start
R1 Mixing Pump:	🟢	Manual	60	
R2 Mixing Pump:	🟢	Manual	50	
Hot Water Pump:	🔴	Manual		

Hot Water Pumps Setpoints

Gas

R1 Hot Water Pump Activation Pressure: 10 kPa
R1 Hot Water Pump Deactivation Pressure: 8 kPa
R2 Hot Water Pump Activation Pressure: 10 kPa
R2 Hot Water Pump Deactivation Pressure: 8 kPa

Electric

R1 Hot Water Pump Activation Temperature: 56 C
R1 Hot Water Pump Deactivation Temperature: 60 C

Feed Preparation

1st Feed Preparation Start Time:
R1 Feed Preparation Delay (sec): 20
Chute Open Time (sec): 25
Min. Solids Vol./Collection Event (L): 25
Water/Solids Ratio: 4.00
Maximum Time for Water Addition (sec): 2000
Macerator On Time During Prep. (sec): 90

Feeding Commence

Feed 1: 25:08
Feed 2: 25:20
Feed 3: 25:09
Feed 4: 25:28
Feed 5: 25:34
Feed 6: 25:07
Feed 7: 25:30
Feed 8: 25:00
Feed 9: 25:30
Feed 10: 25:30

Feeding Volumes/Times

		Calc. Time(s)
R1 Feeding Volume:	600 L	317
R2 Feeding Volume:	600 L	378
R2 Wasting Volume:	600 L	383
R1 Feed Premix Length:	100 sec	

Attempted to download invalid decimal number '.1', index 72.

Pumping control speed and Auto / Manual Modes

Shut down and restart of plant

Information / reset

Feeding timing and volume

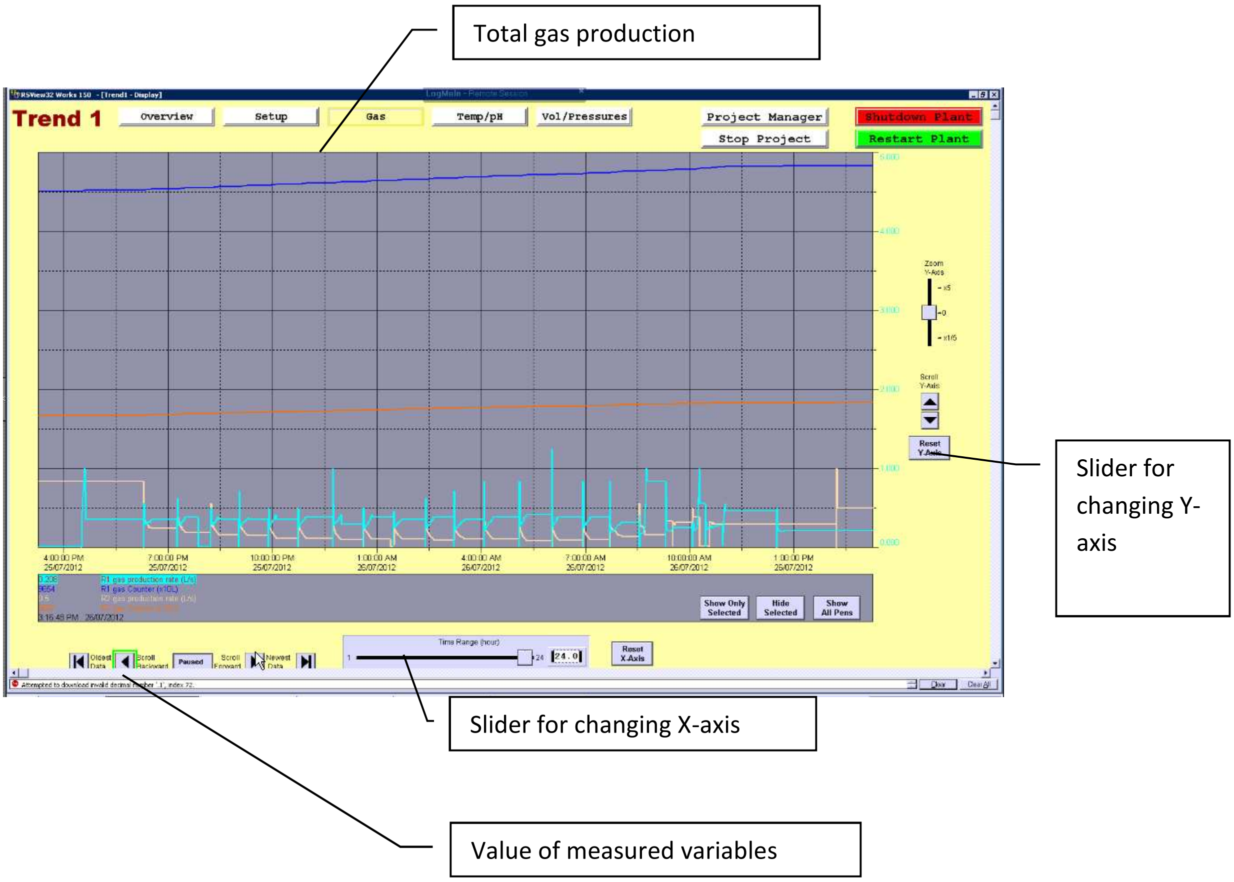
Feeding timing and volume

Feed Preparation Variables

Figure 13: Setup screen of the HMI

The final three tabs allow the user to view a history of the recorded parameters from the plant. The navigation and layout of the screens is the same. The history can be scaled to suit the time frame that needs to be analysed up to the previous 24hrs on the X-axis. The Y axis can also be scaled using the sliders provided. The day can be changed by using the control buttons on the left bottom of the screen.

In Figure 14 is an example of a typical gas tab screen it is possible to view the rate of gas production and when it occurs, this is the two lines at the bottom of the screen and is in Litres / second. The graph is calculated by time per revolutions of the gas meter, so it will produce a flat line when there is no gas production. The volume is totalised by the two upper lines on the graph and this is the total gas produced since the last time the count was reset.



Attempted to download invalid decimal number '.1', index 72.

Figure 14: Example gas production data from R1 and R2

The operation of the software through the HMI is quite straight forward. There may also be reason for advanced users to manipulate the plant directly through the control system, however this is not recommended as this might bypass safety mechanisms and damage the equipment.

4.3.2 Trouble Shooting

Table 7 is a list of trouble shooting hints has been compiled for problems issues that have been encountered during operation of the demonstration plant.

Table 7: Trouble shooting guide

Symptom	Problem	Resolution
Low feed line intake pressure	Blocked feed pipe pre pump	Disassemble piping and clean
High feed line outlet pressure	Blocked Feed line post pump	Disassemble piping and clean
Feed tank level doesn't drop or drops slowly without indication from pressure transducers	Blockage between pressure transducers	Disassemble piping and clean
feed tank fills up unexpectedly	Solenoid is jammed open with object	Disassemble solenoid and clean
Chute stuck open / closed	Possible timing or dirty issue with sensor	Check chute and actuator, reset alarm
	Chute blocked	Check chute and actuator, reset alarm
Feed tank will not fill with water - water time out	Pre solenoid filter blocked	Remove filter and clean
	No process water available	Refer to site manager
	Tank full and overflowing	Reset feed preparation and drain tank
R1 recirculation stops unexpectedly	Mixing nozzle blocked	Remove from top of tank and clear blockage
	Heat exchanger blocked	Remove pipe work after heat exchanger and manually start pump to clear blockage
Manometer blow out	Gas system not running	Refill manometer and check GHWS
GHWS stops working	Possible carbon build up	Open flue and clear carbon deposits / reset GHWS
	Blocked water line	Check filter inside GHWS
	Hot water pump fail	Check operation and circuit breaker
Reactor volume doesn't change over a feed / pumping event	Blocked pump / pipe	Open valves to fine section of pipe that is block, disassemble and clear blockage
Sudden unexpected temperature drop in R1	Solids obstructing probe	Check mass balance of reactors; open and inspect R1 for solids build up
	Broken / faulty probe	Replace RTD
Pump will not run when it should	VSD error	Reset VSD, check for cause
	Obstruction in pump	Open pump and clear object

5 Economics

5.1 Capital Installation

5.1.1 Stage 1

Approximate capital expenditure on the stage 1 demonstration plant was $315,000. A breakdown of capital expenses is shown in Table 8. 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 8: 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**

5.1.2 Stage 2

Approximate capital expenditure to upgrade the demonstration plant to include an automated solids handling system in stage 2 is shown in Table 9. 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 9 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**

5.2 Operating expenditure.

5.2.1 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 is heated using a 12kW electric hot water system when no biogas is available. Biogas produced by the demonstration plant is 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

5.2.2 Electrical Usage:

The primary electrical consumption from the demonstration plant is due to reactor mixing. The pre-treatment reactor is mixed using a 4kW positive displacement pump (50% load). The digester is 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 10: 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

5.2.3 Water Usage

The demonstration plant uses up to 3 kL 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 is not required. A small amount of potable or recycled water is used in wash down and cleaning operations, however this is also minimal.

5.2.4 Operator Labour

The demonstration plant has 2 researchers with an onsite presence of approximately 0.25 FTE each (0.5 FTE total). Operator input largely relates to clearing blockages in process equipment. The frequency of blockages in the demonstration plant is 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) are 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 contributes to this probably by allow material time to settle between feed events. Therefore the feed macerator requires 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.

5.2.5 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 400h 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.

6 Plant Operation/Performance

6.1 Summary

The demonstration plant is treating paunch solid waste at an organic loading rate of 0.5 kg/m^3/day. Over 60% Volatile solids destruction has been achieved during operation with biogas yields of ~240 L methane per kg VS. The biogas has been used to fire an industrial gas hot water system without treatment or conditioning.

6.2 Operating Mode

The demonstration plant operates in semi-continuous mode. There are 10 feed events per day, five days per week. Feed events commence at 8am Monday to Friday are scheduled at intervals of 1h 45mins (start time to start time). Feed events occur as a sequential process where waste material is first pumped from R2 and returned to the onsite waste handling pipeline, pre-treated material is then transferred from R1 to R2, and finally fresh feed is pumped into R1. The total time to complete a full feed sequence is approximately 20 mins. There is 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.

6.3 Feed Material

To date, the demonstration plant has operated on waste material from the green stream. The green stream consists of umbrella wash/paunch and waste from the ante-mortem yards. The waste stream is 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, approximate compositions are shown in Table 11.

Table 11: Characteristics of green waste from Teys Aust. Beenleigh (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

6.4 Lab Based Performance

Biological methane potential (BMP) for green wastewater and paunch cake has been evaluated using batch tests in the laboratory. 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 15. 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.

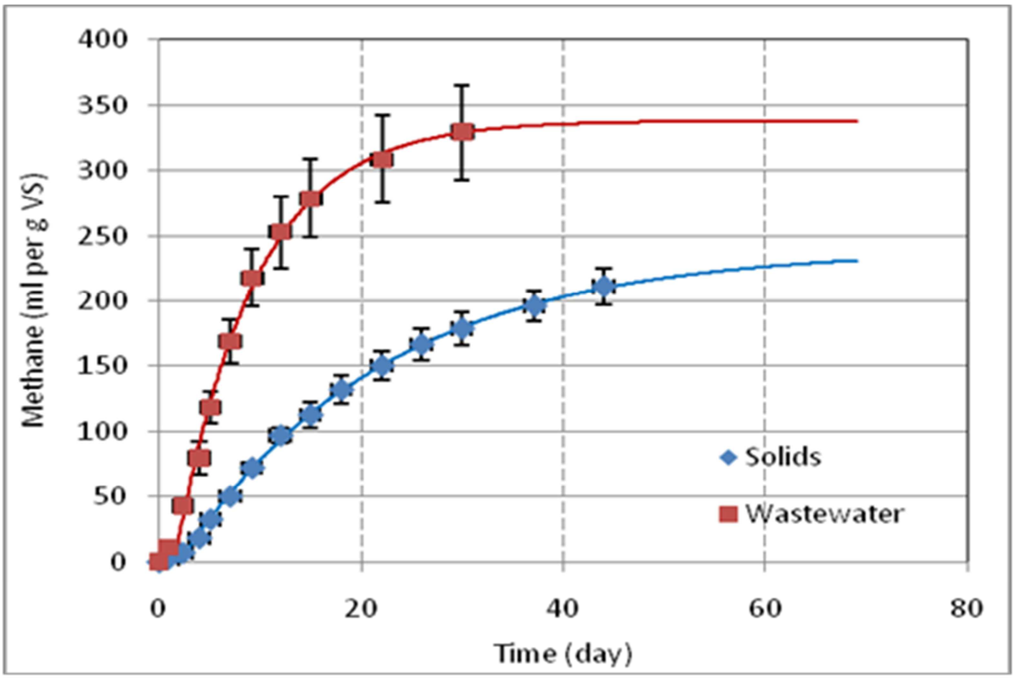


Figure 15: Cumulative methane production (triplicate BMP tests) for paunch solids and paunch wastewater

6.5 Demonstration Plant Performance

Due to blockages and other operational issues, the demonstration plant has been operating with an average loading rate of 40 kg volatile solids per day, or 0.5 kg VS per m^3 per day. This is approximately 40% of the design loading rate. The design organic loading rate is conservative and a full scale implementation should be able to operate at an organic loading rate of 1.5-2 kg VS per m^3 per day.

The demonstration plant is producing approximately 370 L biogas per kg VS added, the biogas composition is approximately 65% methane and 35% carbon dioxide (traces of H_2S are likely), this corresponds to ~240 L methane per kg VS which is equal to the biochemical methane potential predicted during laboratory tests. The biogas is being 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.

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.

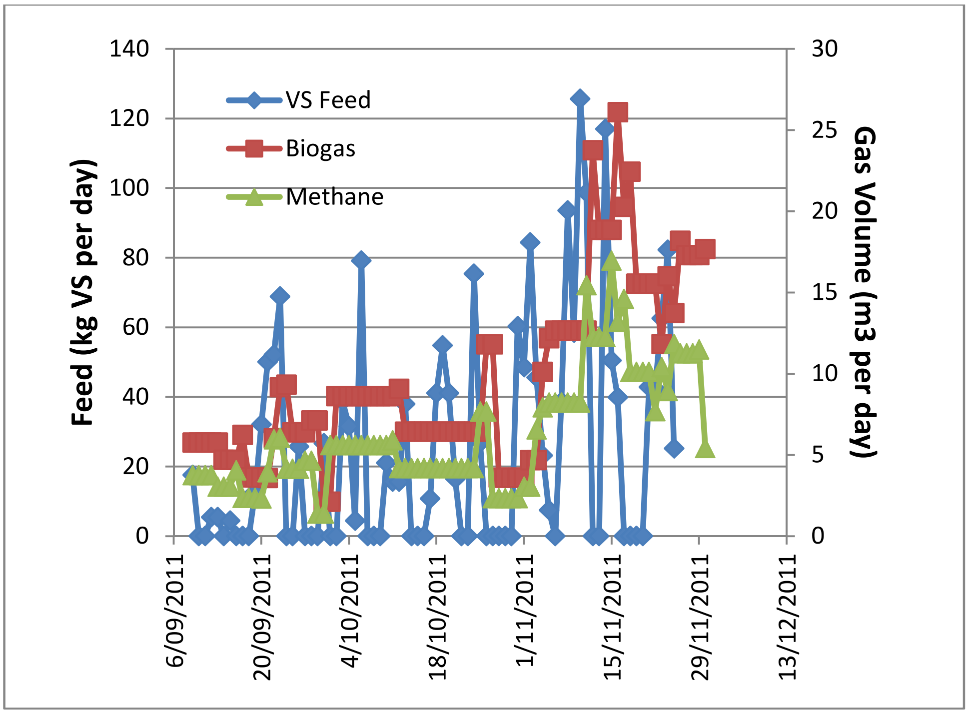


Figure 16: Biosolids Demonstration Plant: Feed Load and Gas Production

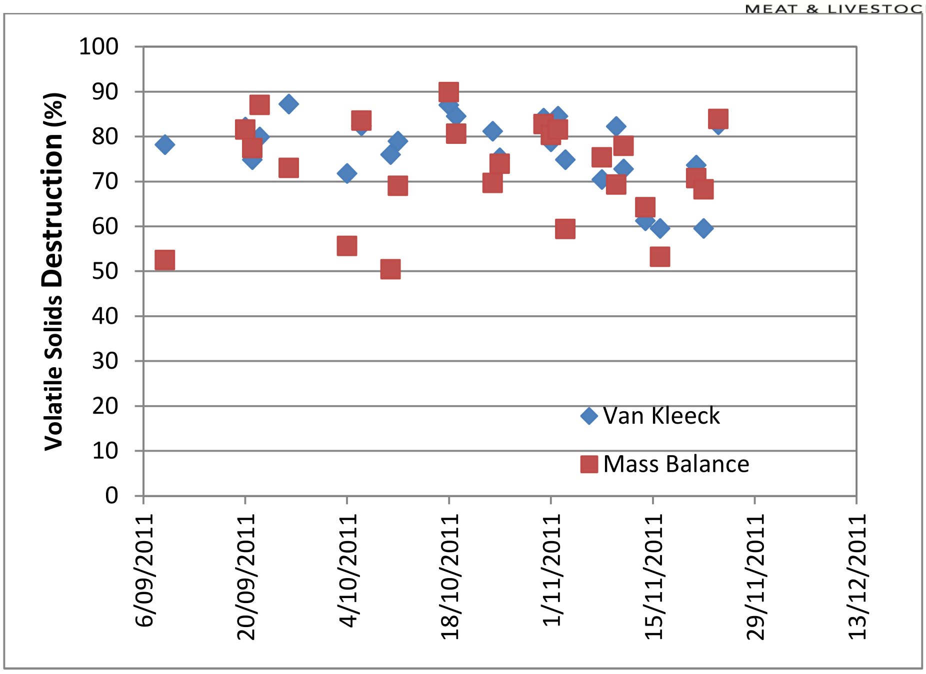


Figure 17: Biosolids Demonstration Plant: Volatile Solids Destruction.

Appendix A Equipment Documentation

A full list of components for the plant has been compiled and is listed in Table 12.

Table 12: Component list of TPAD demonstration list at August 2012

P&ID	Control Room	Number	Make	Description
PLC	PC	1	Intel I7, 3.4GB Ram networked	Dell personal computer
PLC	Software	1	Windows Xp	Microsoft
PLC	Software	1	RSView 32 works 150	Rockwell
PLC	Software	1	RSLogix Micro starter 8.2.00	Rockwell
PLC	Controller	1	Micrologix 1400	Allen Bradley
PLC	Card 1 RTD Input	1	1762-IR4	4 inputs
PLC	Card 2-4 Analogue Inputs	1	1762-IF4	4 Inputs (Total 12 Inputs)
PLC	Card 5-6 Analogue outputs	1	1762-OF4	4 Outputs (Total 8 Outputs)
PLC	Card 7 Analogue Inputs	1	1762-IF4	4 Inputs
PLC	Pump controller	1	Powerflex 4M	VSD 1 Feed Pump
PLC	Pump controller	1	Powerflex 4M	VSD 2 Transfer Pump
PLC	Pump controller	1	Powerflex 4M	VSD 3 Waste Pump
PLC	Pump controller	1	Powerflex 4M	VSD 3 thermophilic Mix Pump
PLC	Pump controller	1	Powerflex 70	VSD 3 Mesophilic Mix Pump
PLC	24 DC Volt Power regulator	1	Mean well DPR 240-24	PLC Power supply
I-4	Current Monitor	1	Carlos Gavazzi D1b01	Monitors current to Mixing pump
PLC	Current Trip switch	1	LR2 D13	Stops Power to Mixing pump on overload
PLC	Circuit Trip Switch	2	NPH Mod6	Cuts power to sump pumps on short circuit
PLC	Intrinsically safe power 4-20mA	1	MTL5544	Two channel repeater power supply for intrinsically safe pressure transducer circuit
	Vessels			
E-1	Feed Tank	1	1.5kL	Feed mixing / storage
E-2	R1	1	20kL	Thermophilic reactor
E-3	Heat Exchanger	1	0.8kL	Shell and Tube
E-4	R2	1	120kL	Mesophilic reactor
	Heating Systems	Number	Make	Description
E-6	Electric hot water system	1	Rheem 61331507	Electric hot water system
E-5	Gas Hot water system	1	Bosch 32 (Biogas modified) model	Biogas Modified Gas hot water system

			KM3211WH	
P-7	Gas hot water pump	1	Davey SS30-25	Hot water pump to activate GHWS
P-8	Electric hot water pump	1	Grundfos ups 25-60 130	Hot water pump to activate EHWS
E-7; E-8	Gas meters	2	ELGAS Model 750 EL40071	Volumetric displacement metering system Physical gas metering for the production of biogas resolution of 1 L,
E-9; E-10	Gas pressure regulators	2	Jeavos J78R	Regulate gas into GHWS
	Pumps	Number	Make	Description
P-1; P-3; P-5	Feed, Waste and Transfer pumps	3	Mono Progressive cavity pump 2.2 kW	Movment of feed / digestate
P-2	R1 Mixing pump	1	Mono Progressive cavity pump 4.4 kW	Reactor Mixing
P-4	R2 Mixing pump	1	Mono Progressive cavity pump 16 kW	Reactor Mixing
	Piping	Length(m)	Make	Description
-	2” uPVC	6	Harvel sch 40	Schedual 40 waste line
-	2” cPVC	18	Harvel sch 80	R1 Recirculation
-	3” uPVC	24	Harvel sch 80	R2 Recirculation
-	3” cPVC	51	Harvel sch 80	R1 feed and Transfer line
-	4” uPVC	6	Harvel sch 80	R2 Recirculation
	Fittings	Number	Make	Description
-	T-Peices	11		For stream split; sample valves
-	90 ^{0} elbows	38		Pipe routing
-	45^0 Elbows	27		Pipe routing
-	1” Valves	7		Ball Valve (sample)
-	2” Valves	4		Ball Valve (For Isolation)
-	3” Valves	6		Ball Valve (For Isolation)
-	4” Valve	1		Ball Valve (For Isolation)
-	Flange	19		Vanstone Flange
	Solids feeding System	Number	Make	Description
P-6	Feed tank mixing	1	Fluid solutions custom S25 DDCM55	0.55kW drive overhead stirring system
C-1	Pneumatic valve	1	Norgran	Air control
C-2	Pneumatic actuator	1	Norgran PRA/182063/M/125	Chute Control
V-1	Process water solenoid valve	1	Danfoss BG024DS	Dilution water control
	Sensors exturnal	Number	Make	Description
I-11;20	Temperature	2	W&B industry SEM203P	RTD 4-20mA
I-14;21	pH Sender	2	Signet 327501	4-20mA
I-3;9;10;18;19	Pressure Transducer	5	Druck PTX1400	-1 to 1.6 bar(g) 4-20mA (Reactor gas phase and feed pump suction)
I-7;8;16;17	Pressure Transducer	5	Druck PTX1400	0 to 4 bar(g) 4-20mA

				(liquid phase)
I-6	Pressure Transducer	1	Genspec GS4200	0-10 bar(g) 4-20mA (discharge feed pump)
I-1	Reed Switch	2	Norgran	Attached to the piston of pneumatic Ram
I-2	Float Switch	1	-	Overfull sensor in Feed Tank
	Saftey	Number	Make	Description
V-27;28	Pressure relif valves	2	-	Open at 17kPa
-	Isolation switches	8	ISO 325pg Katko NPH	Power isolation for pumps
N/I	Mushroom button	0	-	Stop feeding at chute
I-13;14 (N/I)	Pressure transducer	0		Not currently installed

*N/I not currently installed

Appendix B Breakdown of Capital Expenditure

Detailed Stage 1 Capital Expenses

Stage 1 of the EBCRC/UQ Biosolids Demonstration plant was commissioned in 2010. Stage 1 was designed to collect and treat wastewater at the host site. This section of the report included detailed capital costing for each section of the plant.

Foundation

A summary of capital expenditure for the demonstration plant foundations is shown in Table 13.

Table 13: Capital cost of demonstration plant foundation

Foundation	Cost
Geotechnical investigation of site	$5,105.00
Foundation design	$990.00
Concreting	$18,000.00
Construction management	$1,000.00
Bunding - 1m high	$5,000.00
Total	**$30,095.00**

Process Vessels

A summary of capital expenditure for the demonstration plant major process vessels is shown in Table 14.

Table 14: Capital cost of demonstration plant process vessels

Process vessels	Cost
Engineering design and report	$1,700.00
Pre-treatment tank 3m X 3m SS304	$41,152.00
Digester 5m X 5m SS304	$87,119.00
Site work / installation	$21,945.00
Total	**$151,916.00**

Major Process Pumps

A summary of capital expenditure for the demonstration plant major process pumps is shown in Table 15

Table 15: Capital cost of demonstration plant pumps

Pumps	Cost
Pre-treatment Feed Pump	$4,135.00
Pre-treatment Mixing Pump	$4,923.00
Digester Feed Pump	$4,135.00
Digester Mixing Pump	$14,613.00
Waste Pump	$4,135.00
Pump stands (5 @ $1,200)	$6,000.00
Total	**$37,941.00**

Heating Equipment and biogas Management

Capital expenditure for the demonstration plant heating equipment are shown in Table 16.

Table 16: Capital cost of demonstration plant heating equipment

Heating	Cost
Heat Exchanger	$7,500.00
Electric back up unit	$2,000.00
Gas water heater	$1,600.00
Modification and certification	$3,500.00
Total	**$14,600.00**

Process Monitoring and Control Equipment

A summary of capital expenditure for the demonstration plant process monitoring and control equipment is shown in Table 17.

Table 17: Capital cost of demonstration plant monitoring and control equipment

Control system	Cost
Control hut	$6,350.00
PC to run HMI	$1,200.00
HMI and PLC software	$3,000.00
PLC	$20,000.00
Field sensors (pH, level, temp)	$8,000.00
Emergency Relief Valves	$1,000.00
Connection, site work	$10,000.00
Total	**$49,550.00**

Process pipelines

A summary of capital expenditure for the demonstration plant pipelines is shown in Table 18.

Table 18: Capital cost of demonstration plant pipelines

Piping	Cost
Process flow PVC and CPVC	$20,000.00
Gas HWS – copper/stainless steel	$7,500.00
Heat Exchanger – copper/stainless steel	$5,000.00
Total	**$32,500.00**

Detailed Stage 2 Capital Expenses

Stage 2 of the EBCRC/UQ Biosolids Demonstration plant was commissioned in 2011. Stage 2 was an upgrade to the Stage 1 plant designed to collect and treat solid waste at the host site. Therefore Stage 2 used all existing infrastructure from Stage 1. This is section of the report includes detailed capital costing for the Stage 2 upgrade.

Automated Solids Feed Infrastructure

A summary of capital expenditure for the demonstration plant automated solids handling infrastructure is shown in Table 19.

Table 19: Capital cost of demonstration plant automated solids feeding system

Feed System	Cost
Feed tank - existing equipment	-
Feed Collection Chute	$11,500.00
Support Stand	$2,300.00
Direct drive mixer and impeller	$1,650.00
Pipe Work	$5,000.00
Sub Total	**$20,450.00**

Process Vessel Mixing Upgrades

A summary of capital expenditure for upgrades to the demonstration plant mixing system is shown in Table 20.

Table 20: Capital cost of upgrading demonstration plant mixing

Mixing System	Cost
Pre-treatment Reactor	$1,000.00
Anaerobic Digester	$1,340.00
Sub Total	**$2,340.00**

Electrical Infrastructure Upgrades

A summary of capital expenditure for upgrades to the demonstration plant electrical infrastructure is shown in Table 21.

Table 21: Capital cost of upgrading demonstration plant electrical infrastructure

Electrical Upgrades	Cost
Wiring Upgrades	$11,873.00
Field Sensor	$3,000.00
PLC Upgrade	$984.00
Sub Total	**$15,857.00**

Appendix C Piping and Instrument Diagrams

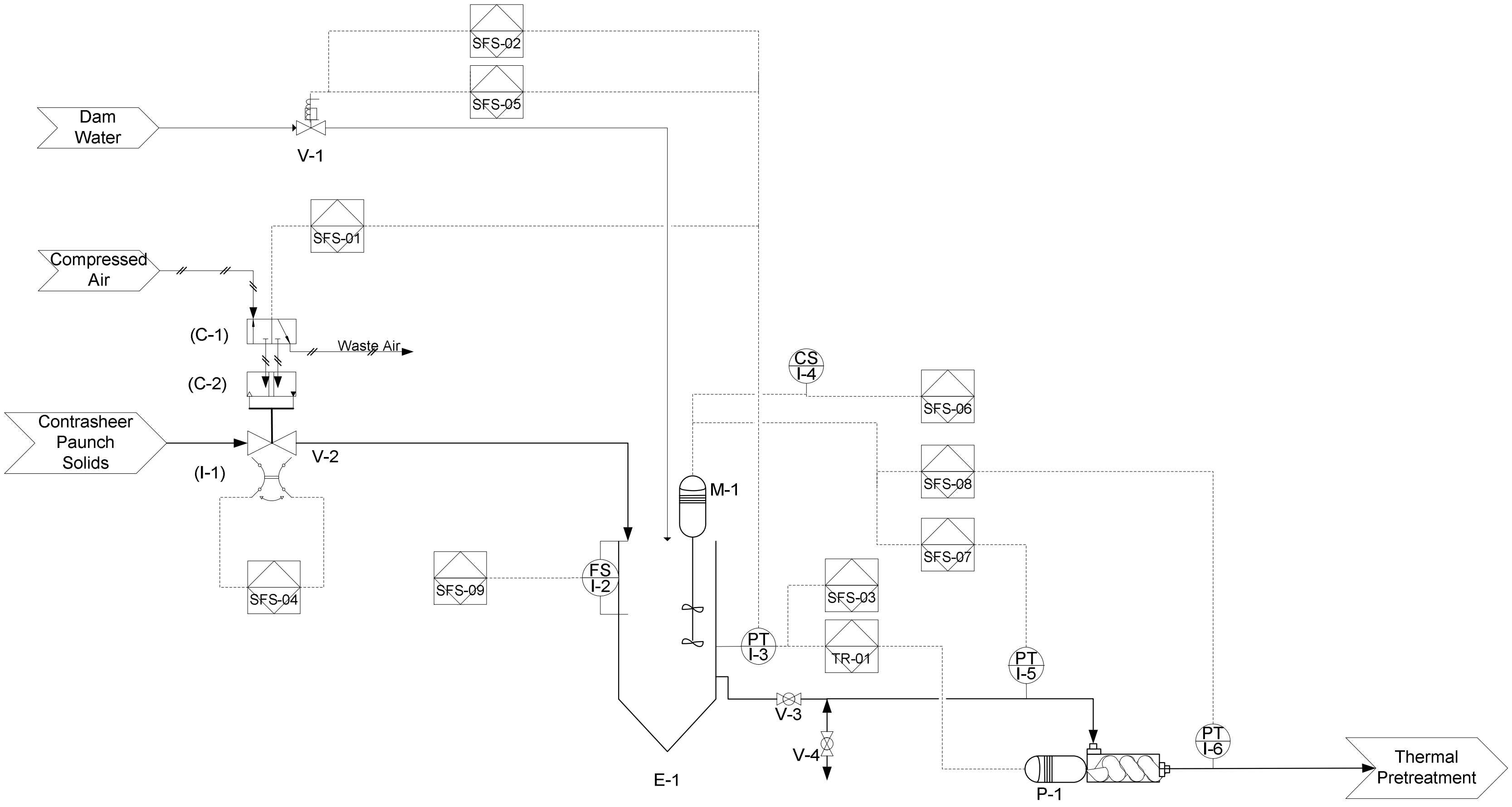


Figure 18: Piping and Instrument diagram – Feed Tank

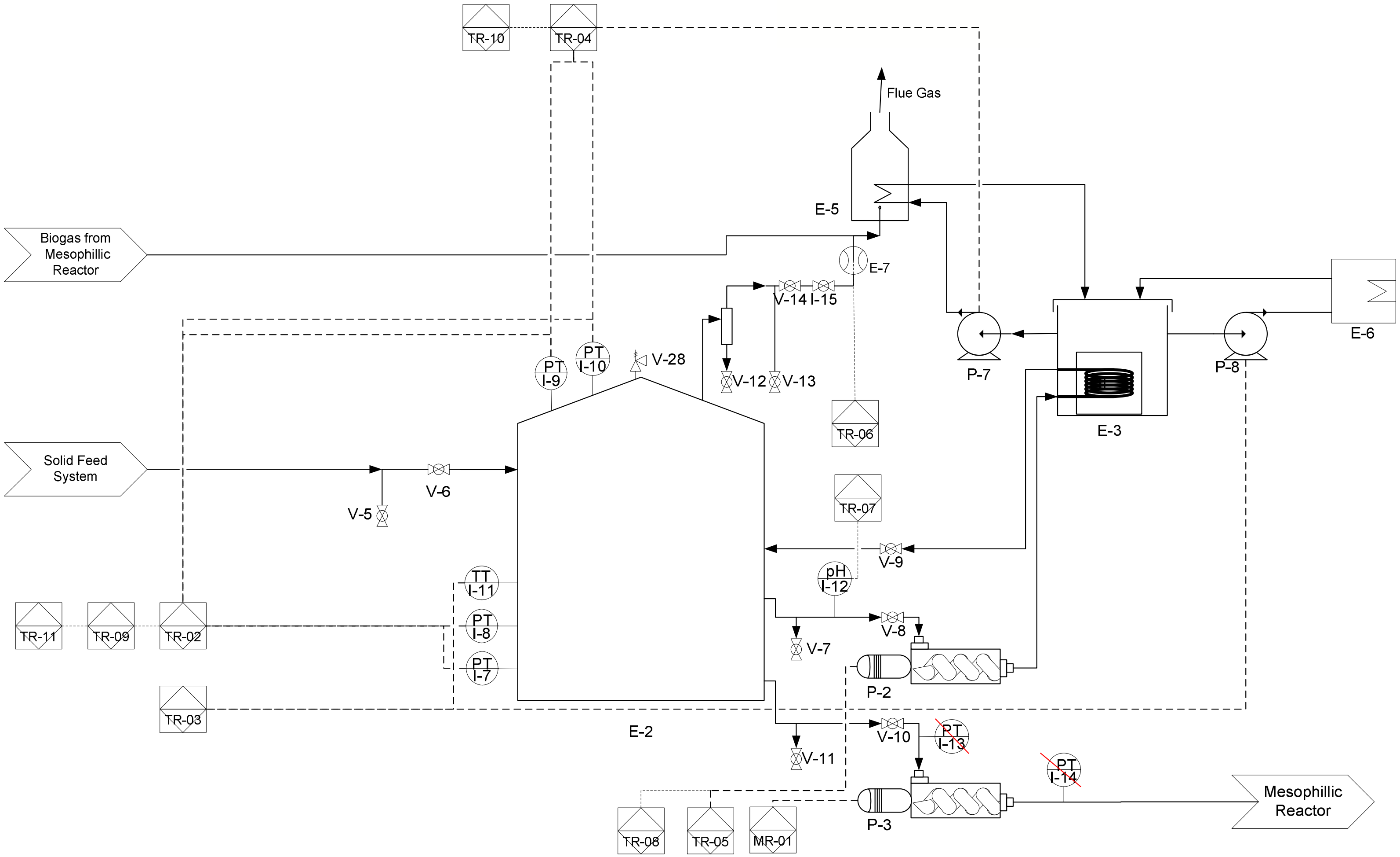


Figure 19: Piping and Instrument diagram – Pre-treatment reactor

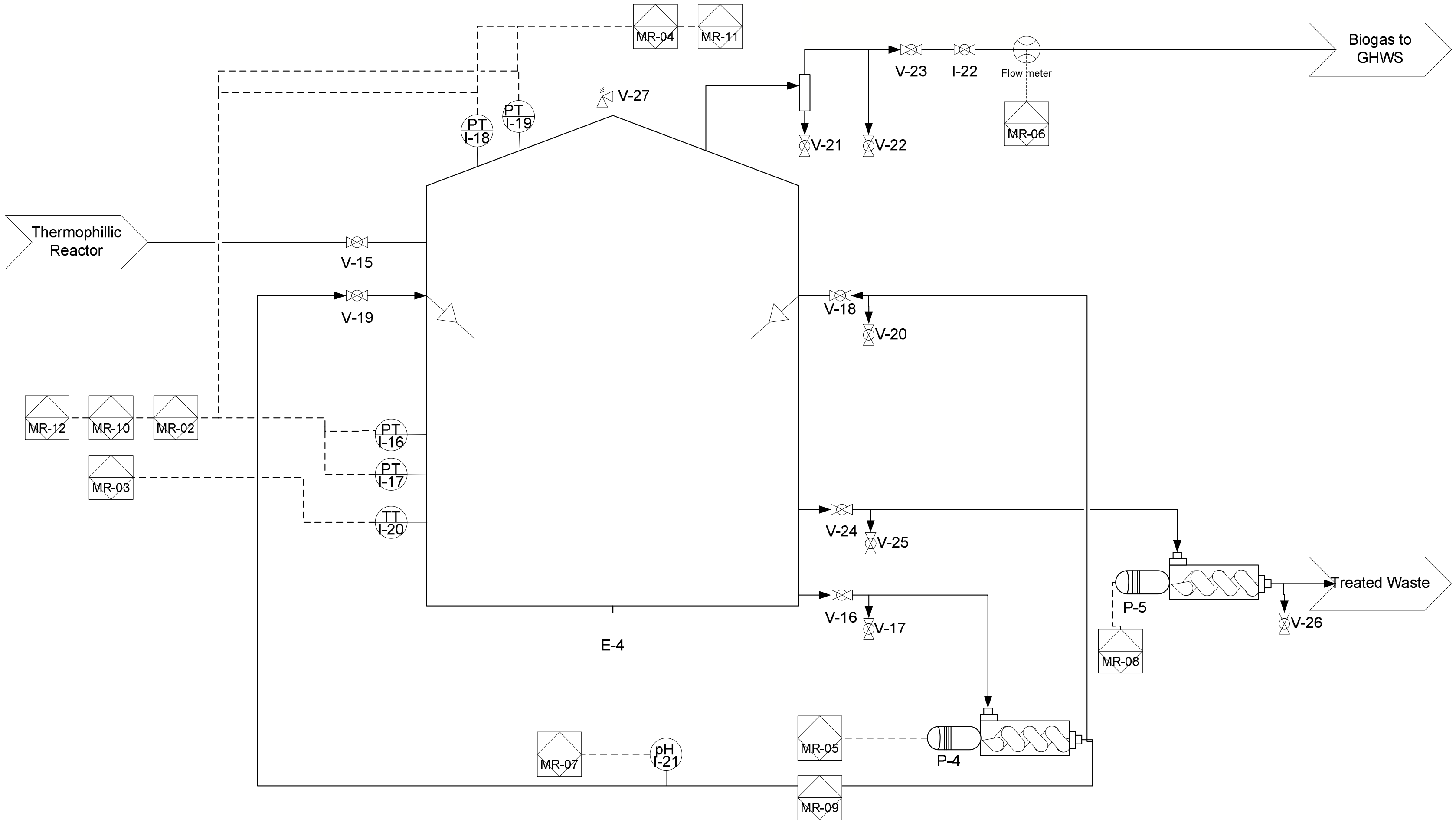


Figure 20: Piping and Instrument diagram –Anaerobic Digester

Appendix D Hazardous Area Dossier