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Design and Optimisation of a Purpose Built Covered Anaerobic Lagoon

Stage 1

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Abstract

This project reports on the design of a purpose built Covered Anaerobic Lagoon (CAL) for a mixed beef and sheep abattoir at Murray Bridge in South Australia. The project includes a desktop review of options and rationale for a final design recommendation for the CAL with specific analysis of key areas of risk including: the design loading rate; an effective automated sludge removal system; a long life covering structure; and a biogas collection and handling system. Importantly, this project also supports the evaluation and review of the theoretical design during the construction and commissioning phases of the CAL development. This includes analysis of any design modifications considered and/or required in translating the proposed design into a functioning plant.

The final design includes two, 20 ML CALs that are operated in parallel, treating a design flow of 3.14 ML/day. The design organic loading rate is 0.54 kgCOD/m^3/day with a hydraulic residence time of 13 days. The design is expected to achieve 80% BOD reduction.

The CALs are gradually stabilising and trending towards the design objectives; achieving 72% BOD reduction as at the end of April 2013. The average biogas production through March 2013 was 0.52 m^3 per kg of COD removed with the average methane content of the biogas being 55%.

Executive summary

Anaerobic lagoons are a cost-effective, low energy technology for the reduction of organic carbon in meat processing wastewater. They are widely used and are the preferred technology in meat processing wastewater systems for initial biological treatment to reduce organic load.

Anaerobic ponds do however have primary weaknesses of odour and greenhouse gas emissions, especially methane which has a global warming potential 21 times that of carbon dioxide. These weaknesses have driven the need to cover the traditional anaerobic lagoon, the Covered Anaerobic Lagoon (CAL) has been developed as a solution.

To consolidate industry knowledge and research in CAL technology, Meat & Livestock Australia (MLA) is creating a knowledge centre around anaerobic lagoons and biogas generation, and wastewater treatment in general. This knowledge centre is a strategic initiative to minimise risks for the whole industry in adopting greenhouse gas mitigating technologies.

This report details the design, construction and commissioning of a purpose built CAL at the Murray Bridge abattoir operated by Thomas Foods International. The CAL is a key component of an overall effluent treatment system upgrade.

Stage 1 of the project includes a desktop review of options and rationale for a final design recommendation for the overall CAL with specific analysis of key areas of risk including:

1. Design loading rate;
2. Effective automated sludge removal system (new technology);
3. Long life covering structure; and
4. Biogas collection and handling system.

Importantly, this project also supports the evaluation and review of the theoretical design during the construction and commissioning phases of the CAL development. This includes analysis of any design modifications considered and/or required in translating the proposed design into a functioning plant.

The final design includes two, 20 ML CALs that are operated in parallel treating a design flow of 3.14 ML/day. The design organic loading rate is 0.54 kgCOD/m^3/day with a hydraulic residence time of 13 days. The design is expected to achieve 80% BOD reduction.

Construction commenced in February 2012 with the site clearing and bulk earthworks. The first design coordination meeting was held on 21 March 2012 with practical completion achieved on 4 October 2012. The construction period was hampered by significant wet weather events.

Commissioning of the CALs commenced on 24 September 2012, with the biogas and flare system commissioned on 26 November 2012.

The CALs are gradually stabilising and trending towards the design objectives, achieving 72% BOD reduction as at the end of April 2013.

The average biogas production through March 2013 was 0.52 m^3 per kg of COD removed with the average methane content of the biogas being 55%.

The pre-treatment technologies at the site are substantially different from other CAL projects supported by MLA. The pre-treatment system allows feedstock to the CAL to be varied and a Stage 2 MLA project will report on this aspect.

Stages 1 and 2 of this project will provide relevant information to fill information gaps in terms of design considerations, biogas optimisation, collection and handling and comparison of CAL performance at a mixed beef/sheep plant compared to a beef plant.

Abbreviations

AMPC	Australian Meat Processor Corporation
BOD	Biochemical oxygen demand
CAL	Covered anaerobic lagoon
COD	Chemical oxygen demand
D&C	Design and construct
DO	Dissolved oxygen
FOG	Fats, oils and greases
HRAL	High rate anaerobic lagoon
HRAS	High rate anaerobic system
kg	Kilogram
kL	Kilolitre (1,000 litres)
km	Kilometre
L	Litre
m^3	Cubic metre (1,000 litres)
mL	Millilitre
ML	Megalitre (1,000 kL; 1,000,000 L)
MLA	Meat & Livestock Australia
TDS	Total dissolved solids
TFI	Thomas Foods International
TN	Total nitrogen
TP	Total phosphorous
TSS	Total suspended solids
UASB	Upflow anaerobic sludge blanket
VFA	Volatile fatty acid

Glossary

Biochemical oxygen demand	The decrease in oxygen content in a sample of water that is brought about by the bacterial breakdown of organic matter in the water (note: BOD_5 is the BOD measured over five days).
Biogas	Gas produced by the breakdown of organic matter in the absence of oxygen. Biogas comprises mainly methane (CH_4) and carbon dioxide (CO_2) and may have some small amounts of hydrogen sulphide (H_2S). Typical composition is: • Methane 50 to 75% • Carbon dioxide 25 to 50% • Hydrogen sulphide 0 to 3% Typical biogas production from anaerobic digestion is 0.5 m^3 per kg of COD removed.
Chemical oxygen demand	A measure of the oxygen demand of organic compounds in a sample of water.
Dissolved air flotation	A water treatment process that clarifies wastewater by the removal of suspended matter such as oils and solids. Tiny air bubbles attach to suspended particles causing the particles to float to the surface where they are skimmed off. A coagulant can be used to flocculate suspended matter which is removed as sludge.
Volatile fatty acids	Fatty acids with a carbon chain of six carbons or fewer. They are formed in the acidogenesis phase of anaerobic digestion and are then consumed in the methanogenesis phase by methane forming bacteria to form methane and carbon dioxide.

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1 Background

1.1 Project Background

Anaerobic ponds are a cost-effective, low energy technology for the reduction of organic carbon (COD or BOD) in meat processing wastewater. Unlike the high rate anaerobic technologies (upflow anaerobic sludge blanket reactors or IC-type systems), anaerobic ponds have proven to be robust and forgiving while achieving greater than 80% organic load reduction. For this reason, they are the preferred technology in meat processing wastewater systems for initial biological treatment to reduce organic load. More than half of Australia's meat processing facilities have anaerobic lagoons.

The primary weaknesses of anaerobic lagoons include:

- Odour emission where natural crusts do not form; and
- Greenhouse gas emissions, especially methane which has a global warming potential 21 times that of carbon dioxide.

Methane emissions from naturally crusted anaerobic ponds currently used by meat processors are responsible for about 50% of Scope 1 emissions for most processors. Capture and flaring (or energy recovery) of anaerobic pond emissions, therefore, substantially reduces greenhouse impacts from modern meat plants with anaerobic pond treatment technology.

Synthetic covers can be fitted over the anaerobic ponds to capture fugitive odours and minimise greenhouse emissions through capture and treatment of biogas. There are numerous Australian examples of their successful use, including for the treatment of domestic wastes, starch industry, distilleries and chicken processing wastes to name a few. The technology is widely used overseas.

In the red meat industry, troublesome failures of anaerobic lagoon covers were experienced at:

- AMH Aberdeen in the late 1990s (outlet blockage with pond rupture resulting in Court action by NSW Government);
- Throsby, Singleton in 2009 (excessive sludge build-up);
- Southern Meats in the late 1990s (hydraulic issues and internal baffle failure);
- Burrangong Meats, Young in 2010 (high sulphur content in biogas and excessive biogas); and
- AJ Bush & Sons, Beaudesert in 2008 (start-up failure with very slow recovery).

These experiences have delayed further implementation of the technology due to the clear risks involved and the severe consequences of failure, especially in a large facility. Previous industry funded projects such as the recently published Meat & Livestock Australia (MLA) report "Anaerobic pond cover vulnerability" (MLA Aug 2009 A.ENV.0072) have tried to address these risks.

The industry is increasingly interested in CALs and MLA/AMPC are encouraging the roll out of this technology. MLA/AMPC are currently supporting two projects that will investigate the performance of alternative CAL designs in different wastewater treatment systems. Project A. ENV.0107 "Using covered anaerobic ponds to treat abattoir wastewater" will investigate the performance of a CAL with a floating cover. Project P.PIP.0290 "Demonstration of covered anaerobic pond technology" will be addressing the performance of CAL technology in a cold climate with limited pre-treatment.

This project will facilitate evaluation of previous research to optimise CAL design and document the rationale. This will also be the first MLA/AMPC are supported application of the technology in a mixed beef/sheep plant.

2 The project

2.1 Objectives

Thomas Foods International (TFI, formerly T&R Pastoral) invested in an upgrade to their effluent treatment system that will support the development of a long term sustainable abattoir system at their Murray Bridge abattoir. The upgrade included the construction of a purpose built CAL that includes technologies to automate sludge removal and manipulate pre-treatment to optimise biogas recovery.

The first stage of this project included a desktop review of options and rationale for a final design recommendation for the overall CAL with specific analysis of key areas of risk including:

1. Design loading rate;
2. Effective automated sludge removal system (new technology);
3. Long life covering structure; and
4. Biogas collection and handling system.

Importantly, this project also supports the evaluation and review of the theoretical design during the construction and commissioning phases of the CAL development. The construction report includes analysis of any design modifications considered and/or required in translating the proposed design into a functioning plant.

The pre-treatment technologies at the site are substantially different from other CAL projects supported by MLA. The pre-treatment system allows feedstock to the CAL to be varied and a Stage 2 MLA project P.PIP.0340 "Manipulation of the newly constructed wastewater treatment system at Murray Bridge to maximise biogas production" will report on this aspect.

Stages 1 and 2 of this project will provide relevant information to the wastewater treatment knowledge centre to fill information gaps in terms of design considerations, biogas optimisation, collection and handling and comparison of CAL performance at a mixed beef/sheep plant compared to a beef plant.

2.2 Murray Bridge Plant

2.2.1 Effluent System Upgrade Project

Thomas Food International operates a sheep and beef abattoir at Murray Bridge, South Australia. The plant processes mixed stock of up to 11,000 sheep and 800 cattle per day. Historically, primary treated effluent (with some fats and solids removed) was pumped to a reuse area and irrigated across about 65 ha of centre pivot irrigation. The irrigation system was dynamic, that is, effluent generated from the abattoir was transferred for immediate irrigation all year round. The system had been operated in this manner for about the past 15 years.

In 2009, Thomas Food International commenced an upgrade of the effluent management system to provide sustainable effluent management into the future. This included:

- plant improvements to reduce effluent generation, improve raw effluent quality and recover more by-products;
- an upgrade to the effluent treatment system to improve the final effluent quality; and
- development of a new effluent reuse scheme.

Objectives of the effluent management system upgrade are to:

- provide an effluent treatment system that meets specified effluent quality targets;
- provide sustainable effluent management for a 25 year planning horizon;
- allow for the recovery and reuse the resource value of the effluent (i.e. methane recovery, nutrient recovery and utilisation, possible water reclamation);
- meet all relevant legislative and licensing requirements; and
- improve environmental outcomes for the local community.

2.2.2 Facility Operation

The plant processes mixed stock of up to 11,000 sheep and 800 cattle per day. The plant operates 5 days per week, 48 weeks per year (plant shut down for four weeks during July each year).

Ancillary facilities include:

- stock holding and handling yards equipped with cattle washing facilities;
- rendering facilities using a continuous high temperature rendering cooker;
- hide processing; and
- offal processing.

2.2.3 Wastewater System

The effluent treatment system at the Murray Bridge abattoir site is made up of the following physical components:

- red and green stream separation and primary screening;
- a save all for gross solids and primary fat recovery;
- a 0.65 ML equalisation tank downstream of an existing clarifier;
- a 250 m^3/hour Dissolved Air Floatation (DAF) unit;
- a 5 ML emergency overflow pond;

- Covered Anaerobic Lagoons (CALs) with biogas collection and flaring (the subject of this project);
- a pump station to transfer effluent from the CALs to the Pahl Farm site; and
- the Pahl farm site, which is comprised of:
  - two 16 ML facultative ponds;
  - a 104 ML detention pond for Helminth control;
  - 260 ML of wet weather storage to balance irrigation demand with effluent generation; and
  - 116 ha irrigation reuse area.

The effluent system schematic is shown in Figure 1.

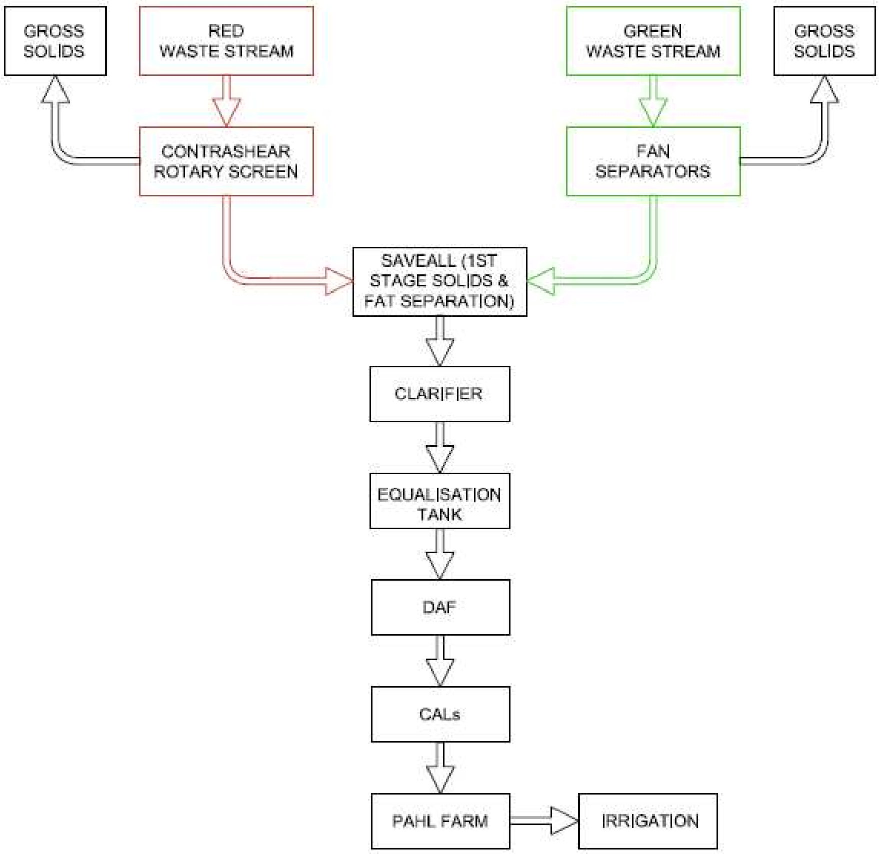


Figure 1: Murray Bridge abattoir effluent system schematic

2.2.4 Design Wastewater Flows

Water reduction initiatives throughout the plant have been successful in reducing the current effluent generation to around 3.1 ML/day on weekdays and 1 ML/day on weekends (average weekly consumption of 17 ML/week).

The effluent system upgrade is based on a design flow of 4 ML/day on weekdays and 1 ML/day on weekends (22 ML/week) which will provide capacity for future production expansion.

This means that system components will have excess capacity in the short term.

2.2.5 Design Wastewater Composition

Prior to plant upgrades and changes to the primary treatment systems, the raw effluent quality was as listed in Table 2.1. This formed the basis for the design of the CAL system.

The DAF is expected to reduce the COD by 20% which will result in a COD to the CAL being approximately 6,900 mg/L

Table 2.1 – Wastewater composition

Parameter	Value 17/06/2009	Value 27/08/2009	Value 23/09/2009	Average
BOD, mg/L	5,000	4,430	9,780	6,400
COD, mg/L	6,300	8,800	10,600	8,570
Oil and grease, mg/L	3,300	980	1,900	2,060
Total Suspended Solids, mg/L	4,400	1,800	2,000	2,730
Volatile suspended solids, mg/L	4,200	1,600	1,900	2,570
Total Dissolved Solids, mg/L	1,700	1,400	1,100	1,400
pH	5.9	6.3	6.6	6.3
Total Kjeldahl Nitrogen, mg/L	250	220	390	287
Nitrate, mg/L	<5	<10	<5	<10
Nitrite, mg/L	<5	<10	<5	<10
Ammonia as N, mgN/L	67	73	66	69
Total Phosphorous, mg/L	51	48	52	50
Phosphate, mg/L	160	110	120	130
Sulphate, mg/L	34	34	5	24

2.3 Approach

Development of the CALs has been through a staged and co-ordinated research, design and construction process as follows:

1. A desktop review of options and rationale for a final decision recommendation for the overall CAL with specific analysis of key areas of risk including:

    - Design loading rate;
    - Effective sludge removal system (new technology);
    - A long life covering structure; and
    - A biogas collection and handling system.

    This is reported in Section 3 of this report.

2. Development of a concept design and calling for a Design and Construction tenders.

    This is reported in Sections 4.2 and 4.3 of this report.

3. Tendering process.

    This is reported in Section 4.4 of this report.

4. Design review and detailed CAL design including effluent quality monitoring to verify effluent loading assumptions.

   This is reported in Sections 4.5, 4.6 and 4.7 of this report.

5. Construction of the CALs and effluent delivery system.

   This is reported in Section 5 of this report.

6. Commissioning of the CALs and effluent delivery system.

   This is reported in Section 6 of this report.

3 Covered Anaerobic Lagoons – A Review

3.1 Desk Top Review

In December 2011 a desktop review into CAL technology was undertaken. The desktop review assessed the design options available for CALs in the red meat industry. The review considered:

- Optimising biogas production and design loading rate;
- Effective sludge removal system (new technology);
- A long life covering structure; and
- A biogas collection and handling system.

3.2 Optimising Biogas Generation

3.2.1 Wastes Entering Wastewater System

Blood has a BOD of about 200,000 mg/L. In terms of blood, cattle tend to have a blood yield of at least 3% of their live weight (or 5.7% of their dressed weight), which yields about 19% solids after drying. The raw blood yield from sheep and lambs ranges from 1-2 kg per animal but values of up to 3 kg per animal have been reported (CSIRO, 2003).

As a consequence, it may be possible that in sheep plants a greater proportion of the blood in the animal is not recovered in the initial sticking/bleed out area, but instead is released throughout the rest of the processing line. This would potentially mean that a greater proportion of the blood ends up in the drain system and entering the wastewater treatment system, rather than in the blood recovery system.

If wool falls to the floor during dressing, it may end up blocking the blood recovery drains unless an appropriate strainer is installed. This may also lead to more blood ending up in the wastewater system during cleaning.

Sheep blood tends to have slightly lower nitrogen levels (1054.4 vs 1177.6 mg% or ~12%) and higher phosphorus levels (7.1 vs 5.7 mg% or ~25%) (Houchin et al, 1938) when compared to beef blood. However, the exact nitrogen and phosphorus levels may depend on feed material. Average values for cattle are blood containing 24,000 mg/L nitrogen and 1,500 mg/L phosphorus.

Sheep manure is different to beef manure in terms of volume and composition. There tends to be less of it when compared to beef manure (22% less for feedlot beef and 62% less for dairy cattle) and the biochemical demand is half that of cattle, but it is much less biodegradable, as indicated by the COD/BOD ratio (Taiganides, 1977). It has less nitrogen than feedlot cattle (~49%), but slightly more (~15%) phosphate. This highlights the need to prevent sheep manure from entering the wastewater system wherever possible and instead being reclaimed as solids without coming into contact with liquid waste streams. Urea (urine) entering the wastewater system leads to ammonia in the wastewater. Average values for cattle are urine containing 148 mg/L nitrogen and 40 mg/L phosphorus. Values for sheep were not found.

Data for different animal waste are listed in Table 3.1.

Table 3.1 – Bioengineering parameters of animal wastes (manures)

Parameter	Symbol	Unit	Feedlot Sheep	Feedlot Beef	Dairy Cattle
Wet Waste	TWW	% TLW/day	3.6	4.6	9.4
Total Solids	TS	%TWW	29.7	17.2	9.3
		%TLW/day	1.07	0.7	0.89
Volatile Solids	TVS	%TS	84.7	82.8	80.3
		%TLW/day	0.91	0.65	0.72
Biochemical Demand		%TS	8.8	16.2	20.4
		%TVS	10.4	19.6	25.4
		%TLW/day	0.09	0.13	0.18
COD/BOD_5 ratio	COD/BOD_5	Ratio	12.8	5.7	7.2
Total Nitrogen	N	%TS	4	7.8	4
		%TLW/day	0.43	0.055	0.043
Phosphate	P_2O_5	%TS	1.4	1.2	1.1
		%TLW/day	0.015	0.008	0.01

TLW = total live weight

Source: Taiganides, 1977

One key difference between beef and sheep processing plants is that dry dumping of beef paunches is relatively easy, whereas dry dumping of sheep paunches is not. This leads to high nitrogen, phosphorus and COD levels entering the primary wastewater treatment system. Sheep paunches are generally directed to a gut cutting and washing system, and then directed to rendering (CSIRO, 1993). TFI have implemented sheep and beef paunch dry dumping.

In a 1995 report (MLA, 1995) investigation at a sheep plant identified the process sources of nutrient and COD. The results are summarised in Table 3.2. This indicated that most of the COD load in the raw effluent comes from the rendering plant (49 kg/tHSCW), then manure/paunch processing (14 kg/tHSCW), then offal processing (5 kg/tHSCW) and slaughter/evisceration (4 kg/tHSCW), with smaller amounts from other areas such as the boning room and casings processing. Interestingly, the sheep plant had higher COD levels (67 kg/tHSCW) than the two beef plants, which were 49 and 28 kg/tHSCW. Similarly, total nitrogen, phosphorus and sodium levels were higher in the raw effluent at the sheep plant than the 2 beef plants (refer to Table 3.3 and Table 3.4). Total suspended solids were not measured at the sheep plant.

Table 3.2 – Nutrient Sources at a sheep plant (Abattoir A), 1995 data

Source	COD kg/thSCW	COD % of Total	Sodium kg/thSCW	Sodium % of Total	NOx % kg/thSCW	NOx % of Total	TKN kg/thSCW	TKN % of Total	TP kg/thSCW	TP % of Total	O&G kg/thSCW	O&G % of Total
Slaughter/ evisceration	4.26	5.8%	0.25	6.9%		0.0%	0.58	20.0%	0.01	1.4%	0.1	0.5%
Offal Processing	5.43	7.4%	0.24	6.6%	0.05	1.7%	0.17	5.9%	0.08	11.4%	1.02	5.0%
Boning Room	0.46	0.6%	0.03	0.8%		0.00.3%	0.17	5.9%	0.001	0.01%		0.0%
Casings processing	0.62	0.8%	0.52	14.4%	0.67	22.60.3%	0.05	1.75	0.01	1.4%	0.02	0.1%
Manure/Paunch	13.64	18.5%	1.61	44.6%	0.18	6.10.3%	0.73	25.25	0.35	49.9%	4.24	20.7%
Rendering	**49.4**	**66.9%**	**0.96**	**26.6%**	**0.14**	**4.7**0.3%	**1.2**	**41.45**	**0.25**	**35.7%**	**15.13**	**73.8%**
Raw material bin	5.69	7.7%	0.11	3.0%	0.004	0.10.3%	0.37	12.85	0.05	7.1%	9.63	47.0%
Tallow processing	2.375	3.2%	0.004	0.1%		0.00.3%	0.01	0.35	0.014	2.0%	0.6125	3.0%
Blood processing	3.24	4.4%	0.19	5.3%		0.00.3%	0.13	4.55	0.013	1.9%	0.03063	0.1%
Cooker condensate	0.36	0.5%	0.0006	0.0%	0.1	0.3%	0.19	6.65	0.0003	0.0%	0.0335	0.2%
Total (summed)	**73.81**		**3.61**		**1.04**		**2.90**		**0.70**		**20.51**	
Total (MLA report)	63.26		2.99		2.96		2.88		0.78		12.43	
Fellmongery	0.6		0.3				0.0006		0.0005			
Pickle plant	2.66		0.74				0.21		0.0085		12.43	
Total – final effluent	66.52		4.03		2.96		3.09		0.52		12.43	
Total (summed)	**66.52**		**4.03**		**2.96**		**3.09**		**0.79**			

Note: NOx = Nitrate + nitrite, TKN = Total Kjeldahl nitrogen = organic N + ammonia N, TP = total phosphorus, O&G = oil and grease

Table 3.3 – Nutrient Sources at a beef plant (Abattoir D), 1995 data

Source	COD kg/thSCW	COD % of Total	Sodium kg/thSCW	Sodium % of Total	Ammonia Kg/tHSCW	Ammonia % of Total	TKN kg/tHSCW	Tkn % of Total	TP kg/tHSCW	TP % of Total	TSS kg/tHSCW	TSS % of Total	BOD kg/tHSCW	BOD % of Total	COD:BOD Ratio
Slaughter/evisceration	5.75833	11.8%	0.17013	12.0%	0.07329	15.1%	0.9318	38.7%	0.02199	5.2%	1.09932	7.6%	3.8996	8.7%	1.48
Offal Processing	3.3	6.8%	0.01455	1.0%	0.03409	7.0%	0.15136	6.3%	0.01409	3.3%	1.18182	8.2%	1.57273	3.5%	2.10
Chillers	0.0103	0.0%	0.00073	0.1%	0.000026	0.0%	0.00083	0.0%	0.000012	0.0%	0.00094	0.0%	0.00562		
Boning Room	0.03383	0.1%	0.00308	0.2%	0.00068	0.1%	0.00088	0.0%	0.000022	0.0%	0.00549	0.0%	0.01263		
Casings Processing															
Manure/paunch	8.12455	16.6%	0.78545	55.3%	0.05155	10.6%	0.34609	14.4%	0.23318	54.7%	2.02255	13.9%	4.00091	9.0%	2.03
Rendering (summed)	**30.65796**	62.7%	**0.20419**	14.4%	**0.25691**	52.8%	**0.8736**	36.3%	**0.11299**	26.5%	**9.9174**	68.4%	**31.63363**	70.9%	
Raw Material Bin	5.71364	11.7%			0.03	6.2%	0.42682	17.7%	0.04091	9.6%	0.87273	6.0%	3.87273	8.7%	1.48
Tallow Processing	20.8536	42.7%	0.02614	1.8%	0.04214	8.7%	0.14787	6.1%	0.04604	10.8%	8.62235	59.5%	25.867	58.0%	0.81
Blood Processing	2.38617	4.9%	0.08958	6.3%	0.08307	17.1%	0.20034	8.3%	0.01222	2.9%	0.28667	2.0%	1.41379	3.2%	1.69
Cooker Condensate	1.62273	3.3%	0.07302	5.1%	0.09015	18.5%	0.09421	3.9%	0.01127	2.6%	0.08474	0.6%	0.31102	0.7%	5.22
Scrubber Effluent	0.08182	0.2%	0.01545	1.1%	0.01155	2.4%	0.00436	0.2%	0.00255	0.6%	0.05091	0.4%	0.16909	0.4%	0.48
Stockyard Washdown	0.98318	2.0%	0.24341	17.1%	0.06968	14.3%	0.10118	4.2%	0.04391	10.3%	0.27109	1.9%	3.49364	7.8%	0.28
Total (summed)	**48.87**		**1.42**		**0.49**		**2.41**		**0.43**		**14.5**		**44.62**		1.10
Total (MLA report)	48.87		1.69655		0.48621		2.40575		0.42618		14.4986		44.62		1.67

Table 3.4 – Nutrient Sources at a beef plant (Abattoir E), 1995 data

Source	COD kg/thSCW	COD % of Total	Sodium kg/thSCW	Sodium % of Total	Ammonia Kg/tHSCW	Ammonia % of Total	TKN kg/tHSCW	TKN % of Total	TP kg/tHSCW	TP % of Total	TSS kg/tHSCW	TSS % of Total	BOD kg/tHSCW	BOD % of Total	COD:BOD Ratio
Slaughter/evisceration	1.16573	4.1%	1.34322	56.3%	0.02159	11.0%	0.08155	8.6%	0.003	5.3%	0.899	7.5%	0.54329	3.2%	2.15
Offal Processing	0.87591	3.1%	0.20881	8.8	0.00841	4.3%	0.06237	6.5%	0.00868	15.4%	0.30915	2.6%	0.48541	2.9%	1.80
Chillers														0.0%	
Boning Room														0.0%	
Casings Processing														0.0%	
Manure/paunch	3.58264	12.7%	0.18822	7.9%	0.01978	10.1%	0.08395	8.8%	0.02166	38.5%	1.10955	9.2%	1.79132	10.5%	2.00
Rendering (summed)	**21.1695**	75.1%	0.23048	9.7%	**0.06629**	33.7%	**0.48067**	50.5%	**0.02288**	40.7%	**8.85089**	73.4%	**13.67228**	80.5%	
Raw Material Bin	0.13976	0.5%	**0.00452**	0.2%	0.00042	0.2%	0.01276	1.3%	0.00162	2.9%	0.03451	0.3%	0.07024	0.4%	1.99
Tallow Processing	17.125	60.7%	0.10375	4.3%	0.00475	2.4%	0.06475	6.8%	0.01725	30.7%	7.85	65.1%	11.3125	66.6%	1.51
Blood Processing	3.65521	13.0%	0.0783	3.3%	0.03819	19.4%	0.32465	34.1%	0.00401	7.1%	0.77917	6.5%	2.21528	13.0%	1.65
Cooker Condensate	0.09675	0.3%	0.00113	0.0%	0.0185	9.4%	0.04375	4.6%			0.00388	0.0%	0.0625	0.4%	1.55
Scrubber Effluent	0.15278	0.5%	0.04278	1.8%	0.00443	2.3%	0.03476	3.6%			0.183333	1.5%	0.01176	0.1%	12.99
Stockyard Washdown	1.40556	5.0%	0.41528	17.4%	0.0805	41.0%	0.24406	25.6%			0.89444	7.4%	0.49833	2.9%	2.82
Total (summed)	**28.20**		**2.39**		**0.20**		**0.95**		**0.06**		**12.06**		**16.99**		1.66
Total (MLA report)	17.95		1.85243		0.22535		0.99306				29.4097		9.93	Average	3.01

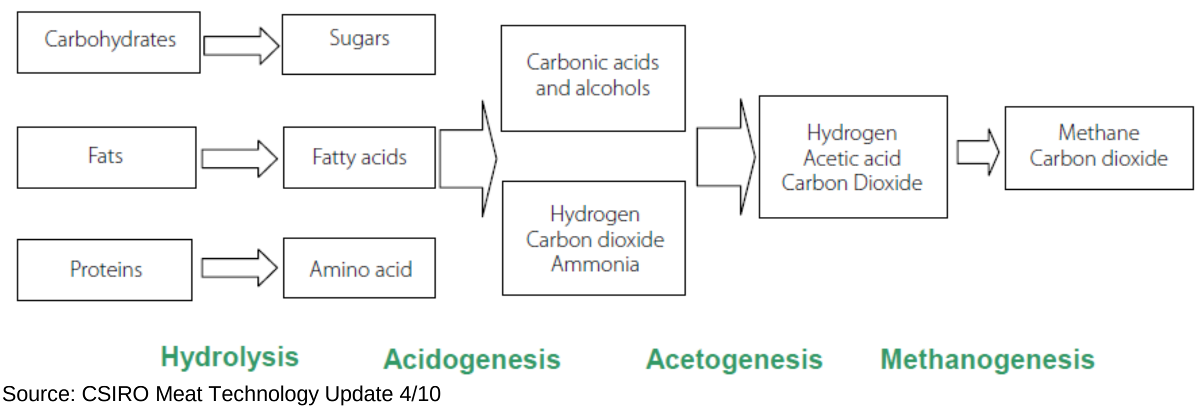
The higher levels are due in part to the operations in the rendering plant. COD and nutrient levels were lower at the beef rendering plants, and there was quite a difference between the beef plants (although both were lower than the sheep plant). In terms of fats, oils and grease (FOG), almost 75% of the total load came from the rendering plant, with nearly 50% coming from the raw material bin drainage. This may indicate an area where a small hydrocyclone could be used on more concentrated streams to remove FOG from the system.

3.2.2 Optimising Wastewater Feeds for Biogas Generation

There are a number of conditions that encourage biogas generation in the anaerobic lagoon, namely:

- absence of oxygen.
- relatively constant temperature, with higher temperatures generally encouraging more rapid biological activity (ideally 30-38℃ for mesophilic bacteria);
- pH between 6.6 and 7.6 in the reaction zone (Metcalf & Eddy, 1979);
- sufficient alkalinity to ensure that the pH will not drop below 6.2 (normally in the range 1,000-5,000 mg/L) (Metcalf & Eddy, 1979);
- volatile fatty acids less than 250 mg/L (Metcalf & Eddy, 1979);
- a consistent supply of feed material for the bacteria to feed on, which is within the design loading of the pond;
- surface area of feed material maximised, by removing gross solids, to provide greater area for bacteria to act on;
- adequate nutrients, such as nitrogen and phosphorus
- removal of non-biodegradable material from the system, particularly solids and grit;
- absence of any toxic compounds, such as chemicals, disinfectants, heavy metals, high levels of sulphides; and
- adequate contact between feed material and sludge, which contains most of the bacterial populations.

Anaerobic digestion is made up of three main stages as shown in Figure 2 (hydrolysis and acidogenesis are normally considered to be the one stage).



Source: CSIRO Meat Technology Update 4/10

Figure 2: Anaerobic digestion process

1. Acidogenic bacteria ("acid-formers"), which are facultative and obligate anaerobes, hydrolyse and ferment complex organic compounds into simple organic acids (volatile fatty acids), alcohols, hydrogen and carbon dioxide, as well as ammonia and sulphide from amino acids.

2. Acetogenic bacteria break down the products of the Acidogenic bacteria to acetic acid, carbon dioxide and hydrogen.

3. Methanogenic bacteria ("methane formers"), which are strict anaerobes, convert the organic acids to methane gas and carbon dioxide.

There is some disagreement as to which is the most critical population. Some researchers suggest that the most important group are the methane formers, as they have very slow growth rates and are therefore normally the rate limiting step in the anaerobic digestion process (Metcalf & Eddy, 1979). According to a more recent CSIRO publication (CSIRO, 2010), the Acetogenic bacteria are the slowest growing and therefore the rate limiting step. An MLA report (MLA, 1999) stated that methane forming bacteria require a detention time in excess of 25 days at 20℃ to prevent washout.

High rate anaerobic systems are generally kept in the mesophilic temperature range (25-40℃) by the use of external heating, such as in a jacketed vessel. Normal operating ranges for a pond system would be 20-38℃, with higher temperatures c orrelated with higher gas production rates. The pond cover will help to exclude oxygen from the process and may also assist with retaining temperature. Even in summer, the average overnight temperature in Murray Bridge drops to below 15℃. In winter, the average minimum temperat ure in Murray Bridge is about 5℃ and the average maximum temperature is below 20℃, so there may potentially be a need for rewarming the pond to maintain biodegradation during winter months.

The influence of climate on biological activity in an unheated pond is accounted for by a pond activity ratio (a temperature dependent K-value) which is determined by the climatic zone the plant is located in. Although meat processing ponds receive wastewater at elevated temperatures due to all the hot and warm water used in production for sterilisation and cleaning, the ambient environmental conditions will contribute to the rate at which energy is lost from the pond, particularly when there is no feed to the pond (such as overnight and on weekends for a one shift, 5 day a week operation). This will also include how windy the location is, which will have an impact on the design of the pond cover.

The pH in the reactor should be kept above a pH of 6.6, to ensure that the acid levels do not inhibit the biological reactions of the acid forming stage, when volatile fatty acids are produced from feed material. Alkalinity will be consumed within the anaerobic process, so it may be necessary to install dosing of the feed to increase the pH so that the water leaving the pond has a pH of above 6.5 and below 7.4. This can be achieved with calcium hydroxide (lime), calcium carbonate, sodium carbonate or magnesium hydroxide dosing. This protects the system against a rapid increase in acid formation leading to a reduction in pH which then upsets the methane forming bacteria, which are sensitive to pH but generally recover quickly.

The alkalinity should be maintained at a minimum of 800-1,000 mg/L to ensure that there is sufficient buffering (Wall et al, 2000).

Fats, oil and grease (FOG) cause problems in anaerobic systems, in part because they take longer to break down due to the long carbon chains. In addition, the chemical characteristics, such as lower density, mean that the oils float and form a layer on top of the water, which can disrupt gas collection and impact on the cover. In the process, other solids may adhere to the FOG and biological activity on the surface (or surfactants in cleaning chemicals) may create bubbles which are captured within the oily matrix, creating a foam layer which is quite stable. This can accumulate over time if the rate of FOG addition is not matched by the rate of breakdown in the system.

Therefore, upstream removal of FOG is desirable. This can be through use of systems such as dissolved air flotation and hydrocyclones. Hydrocyclones are very sensitive to solids, so there needs to be adequate upstream removal of solids for them to work effectively on red streams. FOG has the potential to adversely interact with the pond cover, causing accelerated degradation of the cover.

Despite the presence of sulphur in the feed material, sulphur levels do not seem to create an inhibitory effect in most covered anaerobic lagoon systems. This is possibly due to the high pH of the reactor, which means that most of the sulphide exists in the system as hydrogen sulphide, which is released from the system as a gas, rather than hydrogen sulphite in solution.

Gas production and the ability for COD reduction decreases when the system is hydraulically overloaded, as insufficient residence time exists for wastes to undergo full treatment and bacteria end up being washed out of the pond. Causes of hydraulic overload include a decrease in volume due to accumulation of grit or sludge, an increase in influent volumes and insufficient freeboard volume, an accumulation of oil and grease on the top of the water and stagnant zones or short circuiting in the pond. At times and depending on the depth of the pond, there may also be thermal stratification, with little vertical mixing.

It is important to screen out non-biodegradable material, particularly if it is solid, as it will simply accumulate in the pond and reduce the effective pond volume. In the Cargill Wagga example, this was achieved on the wastewater coming from the green stream and cattleyards by installing a short hydraulic residence time device to remove rocks and other heavy objects, then a screw press, then a hydrocyclone downstream, then a DAF. On the red streams, the wastewater was directed through a contrasheer, then through a DAF with pressurised clarified effluent to cope with the high temperatures and solids loads. The overall aim was to achieve superior solids removal before the anaerobic system.

Another option in addition to installing adequate solids removal in the primary treatment system would be to include something like a Mono Muncher in the pond influent line, which is used to macerate raw feed material and reduce the size of material entering systems such as sewage treatment plants.

In terms of chemical entering the system, it may be possible to consider the biodegradability of chemicals used and rationalise and minimise the use of disinfectants wherever possible. It is understood that food safety is a key business driver, but within that requirement there may still be potential to use less toxic or more degradable chemicals. It is also unclear to what extent the surfactants used in chemicals contribute to the formation of the floating layer on meat processing anaerobic ponds.

3.2.3 Optimising the Design of the Anaerobic Process

High rate anaerobic systems (HRAS), such as Upflow Anaerobic Sludge Blankets (UASB) and Anaerobic Filters, have been found to be unsuitable for meat processing effluents due to their high FOG and total suspended solids levels (Johns, 2009). These systems have loading rates of up to 10 kg BOD/m^3/day, whereas a normal uncovered anaerobic lagoon has a design loading of 0.2-0.3 kg BOD/m^3/day (CSIRO, 1993) and a covered anaerobic lagoon has a design loading of 0.6-2.4 kg BOD/m^3/day.

One modification of the HRAS is the High Rate Anaerobic Lagoon (HRAL), which has a loading rate of 0.1-0.4 kg BOD/m^3/day for the wastewater treatment industry. This system could be similar in design to an anaerobic contact process, except that there are not two separate vessels (digester and clarifier); rather the sludge clarification occurs in the back end of the pond. This may be useful in the TFI case, where the pond will be rectangular rather than square, due to the dimensions of the site. The first half of the pond could act as the contact process, with influent addition, and then the back end of the pond could act as the clarification or settling stage, with sludge removal.

Anaerobic contact processes have loading rates of 2-5 kg COD/m^3/day, and the COD:BOD ratio is normally about 2:1 for meat processing wastewaters. In this system, wastewater is fed into the bottom of the lagoon through a number of inlets spread across the base of the pond, so that the feed can percolate up through the sludge layer at the bottom. There is a weir system around the edge of the lagoon that collects water for recycling to the inlet, with an internal weir system so that once the recycle flows are met, the remaining overflow is directed to the next pond in the system. The cover is attached to a concrete anchor beam with stainless steel fixtures which allows the cover to be fully or partially removed for maintenance or sludge removal. The recycling of effluent to the feed allows the biomass on the bottom of the lagoon to be “mobilised”, that is, to create mixing.

A typical HRAL system is shown in Figure 3.

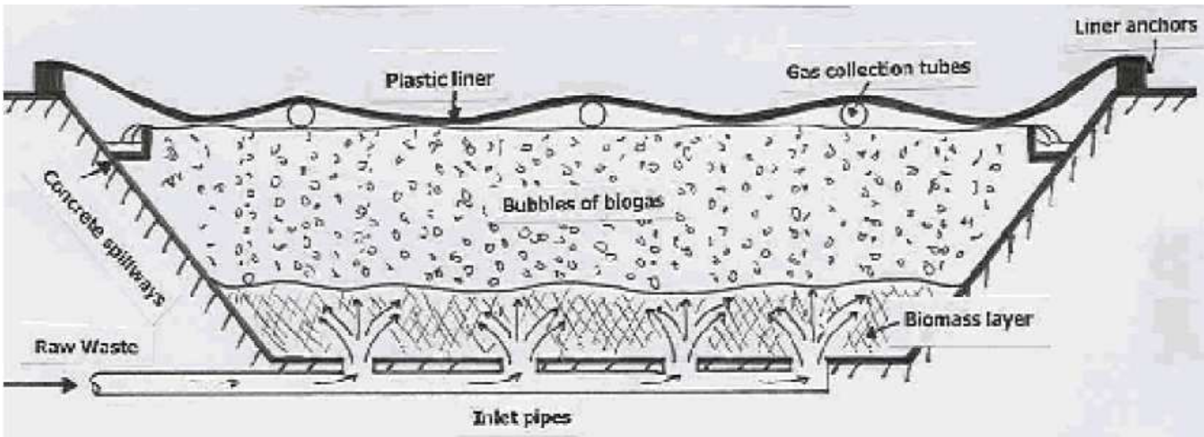


Figure 3: High Rate Anaerobic Lagoon System, used by Goulburn Valley Water to treat food processing wastes (Source: Wall et al, 2000)

COHRAL™ (Covered High Rate Anaerobic Lagoon) is a high rate covered anaerobic lagoon system developed by Global Water Engineering. This lagoon is equipped with an influent distribution system at the bottom of the lagoon to allow a good distribution of the influent and good contact between the influent and the sludge present in the lagoon which improves the performance and stability of the system. No additional mixing facilities are installed in the anaerobic lagoon as the influent distribution system acts as a hydraulic mixing system driven by effluent recycle (pumping).

One key issue mentioned repeatedly is the positive impact mixing has on gas generation rates and required residence times, but the negative impact this can have on retaining the biomass in the pond if mixing is too vigorous – that is, it is a delicate balance. Mixing has a number of benefits, namely minimising the amount of dead zones in the pond and increasing the contact between the bacteria and organic load. Mixing can be achieved by using impellers, recycling sludge, gas up-flow and distribution of inflow.

A Rural Industries Research and Development Corporation (RIRDC) report (RIRDC, 2008, 2) reviewed the use of CAL in the intensive livestock industry, and identified the use of an “enhanced CAL”, where pipes are fitted to collect solids and recycle them back to the lagoon so that there are increased solids retention times and mixing in the lagoon. It identified that the solids recycled are often heated to improve performance, which is probably a key consideration in cold countries such as Canada and the US.

3.2.4 Organic Loading Rates

Various published organic loading rates are listed in **Table 3.5**.

Table 3.5 – Organic loading rates

Type of Lagoon	Organic Loading Rate, kg/m^3/day	
	COD	BOD
HRAL (Wall, 2000)	-	0.1 – 0.4
Covered anaerobic lagoon (CSIRO, 1993)	-	0.6 – 2.4
Covered anaerobic lagoon (UNSW CRC for Waste Management & Pollution Control, 1998)	0.5 – 1.4	-
Southern meats covered anaerobic lagoon – trial target (UNSW CRC for Waste Management & Pollution Control, 1998)	1.0 – 1.20	
Southern meats covered anaerobic lagoon – achieved (UNSW CRC for Waste Management & Pollution Control, 1998)	0.53	
Uncovered anaerobic lagoon (CSIRO, 1993)	-	0.2 – 0.3
Uncovered anaerobic lagoon (UNSW CRC for Waste Management & Pollution Control, 1998)	0.5 – 0.7	-

The Southern Meats project (UNSW CRC for Waste Management & Pollution Control, 1998) was aiming to get a loading rate of 1.0 to 1.2 kgCOD/m^3/day with a hydraulic residence time (HRT) of 5 days. The pilot lagoon got to an OLR of 0.53 kgCOD/m^3/day (HRT 10 to 12 days) due to poor design and construction of the wastewater distribution system and internal baffle system. The trial achieved about 80% COD removal at this loading rate.

3.3 Effective Automated Sludge Removal System

3.3.1 Amount and Timing of Sludge Removal

It is expected that sludge will only need to be removed intermittently, ranging from twice yearly (Davies, 2005) to once every 1 to 2 years (Johns, 2009). There is a delicate balance between building up sufficient, robust biomass in the anaerobic system to be able to treat the effluent, and an excess of sludge causing reduced residence times and high levels of solids in the CAL effluent. The exact timing for sludge removal will be determined by the system feed and design (residence time, temperature etc), and will be indicated by solids carryover in the CAL effluent.

The approximate amount of sludge generated will be 0.04–0.14 kg sludge per kg of COD removed (Parker et al, 1981). More than 80% of the sludge will pass through a 0.075 mm mesh screen (CSIRO, 1993). Combined with the loading rate of 0.1-0.4 kg BOD/m^3/day and assuming a COD: BOD ratio of 2:1 (MLA, 1998), this means that 0.008–0.112 kg sludge produced/m^3/day. The density of the sludge will determine how quickly the pond will reach capacity.

A subsequent report (MLA, 1999) identified that the settled sludge layer provided a supply of methane forming bacteria for reseeding the water column, and so that regular, partial draw off of settled sludge was preferable to less frequent, larger removals of sludge.

3.3.2 Characteristics of Sludge to be Removed

If automated sludge removal is to be achieved, then feed into the pond must be screened to prevent non-biodegradable solids, such as grit, sand, dirt, rags and other debris, from entering the pond. These are likely to cause obstructions in both the collection pipework and the pumping system.

Although it has been assumed that most of the non-biodegradable particulate matter has been excluded from the influent, some will remain. This is represented in Figure 4 as the sludge layer and explains why the A J Bush Riverstone sludge removal system is slightly off the pond floor.

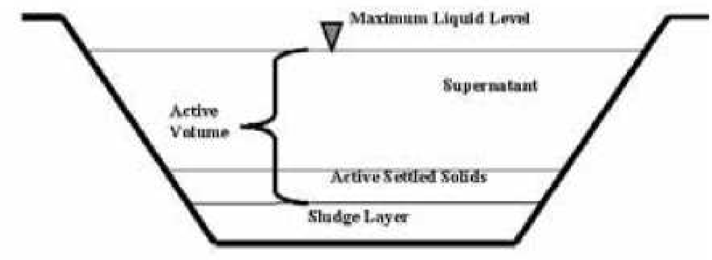


Figure 4: Conceptual components of a treatment lagoon (Chastain 2006)

Active settled solids from the anaerobic digestion process will settle on top of the sludge layer. A previous report (MLA, 1999) identified that the settled sludge had poor flow characteristics with 2-8% solids, which makes it extremely viscous, requiring a large static head (~2 m) and made draw-off problematic given the large area of the pond floor. This means that multiple draw-off points are required and that partial entrainment of liquid is common. In long draw-off pipes, it is easy to see how the area around the closer points would clear first and then water would be preferentially drawn in from these locations, leaving sludge in the sections of the pipework which are further out. This may be overcome by increasing the size of hole in the sludge removal pipework the further away from the pump it is. However, settled sludge which does not contain non-biodegradble material will not form a steep grade, so a large area should be drained with minimal liquid entrainment as the sludge continues to flow in and fill the void left by the withdrawn sludge (MLA, 1999).

3.3.3 MLA Existing Knowledge

The issue of continuous anaerobic pond desludging was covered in an earlier MLA report (MLA, 1999). The key findings are summarised as follows:

- Mechanical scrapers are not practical due to large spans involved (and potential for damage to pond liner).
- Sludge draw off by suction draw off is extremely difficult if long suction lines are used, so either very short suction lines must be used or reliance must be made on the static head of the lagoon to induce sludge flow.
- Anaerobic ponds encourage the formation of struvite and other compounds, which can form scale deposits in the sludge draw-off pipework which restricts the flow rate.
- Small, frequent withdrawals of sludge are preferable to complete removal of all sludge, to ensure that settled sludge can act as seed sludge. This also assists with preventing sludge consolidation, which increases the resistance to flow and makes draw-off more difficult.
- It is likely that grit will rapidly settle near the inlet, and will require velocities in excess of 1.2 m/s to transport them, therefore grit removal before the pond is highly preferable.

- The particulate organic fraction, such as grass, straw and hair, tends to form clumps, mats or strings, and will require a velocity of 0.9 m/s for removal, so pre-treatment of the waste stream to prevent these entering the pond is preferred.
- Active bacterial component of sludge is expected to be 90% water, with a specific gravity only a few percent above water, so will require only 0.15 m/s to ensure transport.
- Aim is to minimise liquid entrainment.
- Grading of pond base, for example to inlet end where most sludge accumulation occurs, may be feasible, particularly in deep ponds.
- Use of mechanical mixer to “blow” sludge to draw-off points may be feasible.

3.3.4 Sludge Removal in Recent Meat Industry Projects

One recent installed project is A J Bush at Riverstone. Rows of sludge piping were installed on the bottom of the pond, with the pipes running through the side of the HDPE pond lining (refer to Figure 5). The pipes are 200 mm HDPE, extend 90% across the 28 m width of the pond bottom and are suspended 150-200 mm off the floor. The holes in the pipe are 30 mm holes in diameter, there are 12 holes per pipe (i.e. about every 2 m) and located at positions alternating between the 4 o’clock and 8 o’clock position. Any high points in the pipe have smaller holes in the top, so that any gas that accumulates in the pipes can be released. The pipes are evenly spaced along the 39 m length of the pond, so about 6-7 m between them. The pipes have valves on the outside of the pond wall and the idea is that a vacuum suction truck would be brought onsite when the sludge needs removal.

Figure 5: Sludge Removal Pipes, A J Bush Riverstone (Source: A J Bush)

The sludge pipes are designed to be weighed down with simple sand filled pipe sections, as a means of ensuring that the pipes do not start to float if they end up with gas accumulating inside of them due to biological activity (refer to Figure 6).

Figure 6: Weighting of Sludge Removal Pipes, AJ Bush Riverstone (Source: AJBush)

The sludge removal system at Bears Lagoon piggery appears to have 4 attachments on the pond cover, with the sludge pipes resting on top of the pond cover, and the sludge pump located on the top of the bank of the lagoon.

3.3.5 Sludge Removal in Other Industries

APL funded trials for in-situ desludging of an anaerobic lagoon that was uncovered (APL, 2008). It looked at three methods: a mono pump, a SludgeRat (from UAT, an Australian manufacturer) and a Kato long reach excavator and truck. The SludgeRat (and related system, such as the SlurryRat in Figure 7) is a floating suction dredge, designed to remove sludge from the bottom of ponds up to 3 m deep (with modifications required for deeper ponds) and up to 9% biosolids. The SludgeRat removed more sludge than the other methods and was capable of desludging the entire lagoon area, but had lower solids content. UAT have done work on systems for covered ponds with Melbourne Water, and have designed systems which are static or move in the pond, and are removable. For a removable system, the pond system needs to be designed with an entrance and exit point. UAT advises that if a plant is to use pipes on the bottom of the pond, then care needs to be taken that the influent is screened to remove solids and that the sludge is turned over regularly, otherwise the sludge will compact and will not flow.

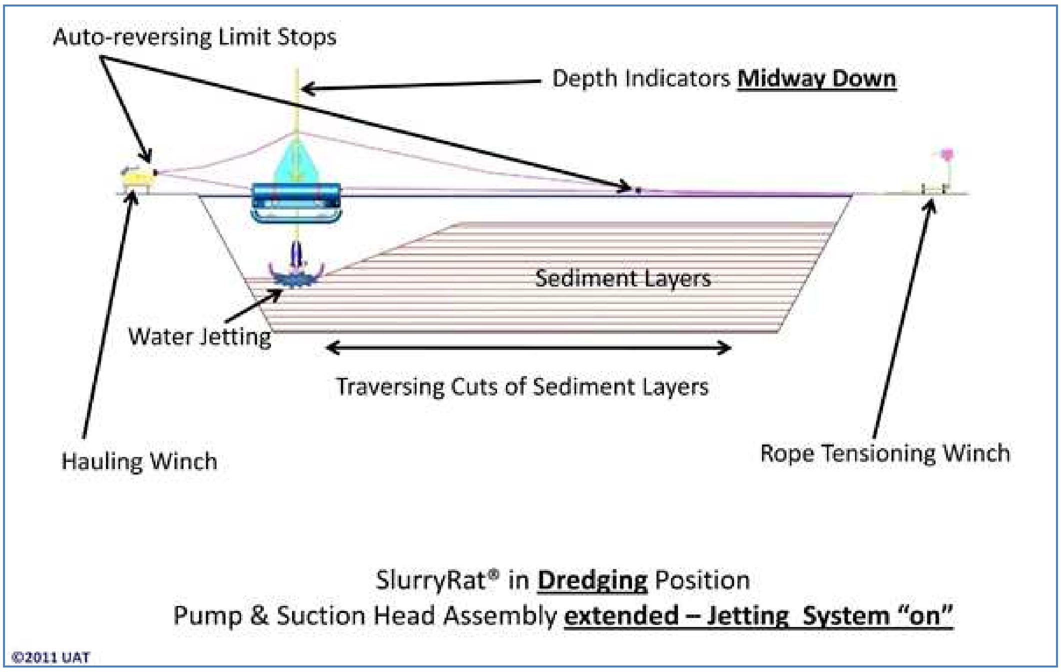


Figure 7: SlurryRat, UAT (Source: UAT website)

As part of a RIRDC study on biogas produced from a CAL at a piggery (RIRDC, 2010), sampling was conducted to determine the volume and characteristics of sludge in a CAL that was treating spent bedding from deep-litter housing of pigs. A 12V open-impeller submersible pump (OD 50 mm) was attached to a graduated steel probe and lowered down into the water column through the emergency gas vents. A 12 mm HDPE tube delivered the discharged sludge back to the surface for sampling. Samples were collected at 0.5 m intervals starting at 2.0 m and progressing to the bottom (or the depth at which the solids content of the sludge exceeded the pump capabilities) at vent locations 2, 5 and 8 (2 being the second vent numbered from the inlet end of the CAL). The depth at which the discharge changed colour from brown to black was noted at each vent, as an indication of the transition from the settled sludge to supernatant zones in the pond.

A study by APL (2008, 1) stated that "for CALs, common practice is to periodically desludge the lagoon using a "sludge rat" pump or similar". A RIRDC report from the same year (RIRDC, 2008, 3) that reviewed an earlier study at Parkville Piggery at Scone stated that "there was no known system in Australia that allows for sludge removal without the cover being removed".

A 2010 RIRDC report on the Bears Piggery lagoon found that the boundary between the settled solids and supernatant was readily identifiable, as the colour changed from brownish (supernatant) to a much darker substance, often black in colour. In terms of volume, the active settled solids and sludge layer accounted for 58% of the total pond volume. At a depth of 5 m from the surface (with a total pond depth of 7.48 m) the total solids level was above 12% and the submersible pump used to extract material via the 50 mm gas vents could not deliver any discharge. The study found that total solids (TS) and volatile solids (VS) decrease with depth at a reasonably uniform rate. The study found that at 5 m, a decrease in the proportion of VS occurred, which may indicate a transition to sludge which is less active in the breakdown process. This system was designed to only enable sludge recycle to the inlet, but not for sludge discharge from the system. The system was designed with 4 separate points along the length of the pond, but the report found that more research was required to identify how frequently and for what duration the system should be operated to control sludge build up and prevent blocking of the inlets. The pump used was a positive displacement helical rotor type, with 110 mm HDPE pipework so the flow velocity was 0.85 m/s, with a discharge of 6 L/s. One of the 4 inlets had solidified and had to have the solids removed by vacuum pump, as the main pump would not prime and the stator was damaged during one attempt at pumping after 5 years of the pond operating without any sludge removal. In this instance, it appears that the sludge pipes were attached to fixtures on the top of the lagoon cover, rather than the AJ Bush Riverstone system where they go out through the side wall of the lagoon.

3.4 Long Life Covering System

3.4.1 Cover Material

The most recent, details report on covers was completed in 2009 (MLA, 2009), a summary table is included as Table 3.6. At times, there is a balance between odour and cover life – for example, it terms of minimising odour, a negative pressure system would inherently reduce the risk of biogas release. However, it is likely that the cover would come in contact with the liquid, leading to volatile fatty acid attack of the cover. In some of the older projects, such as the Camilleri pond designed and installed by AGL, the cover was only guaranteed for 10 years. A summary is provided in Table 3.7 of key design principles to be adopted. Hydrogen sulphide odour becomes offensive at 3-5 ppm, so even small amounts are likely to cause odour problems given how close the nearest neighbours are to the CAL at the TFI site.

Table 3.6 – Relative comparison of materials for anaerobic pond cover

Cover Material	HDPE	LLDPE	fPP	R-EIA	CSPE
Material Supply Cost	Least Expensive	Similar to HDPE	More Expensive than LLDPE	More Expensive than fPP	Most Expensive
Flexibility	Poor Flexibility	Good Flexibility	Best Flexibility	Very Good Flexibility	Very Good Flexibility
Resistance to Wind Uplift	Good Wind Resistance	Good Wind Resistance	Poor Wind Resistance	Moderate Wind Resistance	Highest Wind Resistance
UV Resistance	Good UV Resistance	Moderate UV Resistance	Good UV Resistance*	Good UV Resistance*	Good UV Resistance
FOG Resistance and Durability	Good FOG Resistance	Moderate FOG Resistance	Poor FOG Resistance	Good FOG Resistance	Good FOG Resistance
In-service Repair	Easy to Repair	Easy to Repair	Difficult to Repair	Moderately Easy to Repair	Most Difficult to Repair
***Dependant on formulation**					

Source: MLA (2009)

Table 3.7 – Design consideration for longevity and odour minimisation

Issue	Design Consideration
Reduce potential for chemical attack on cover	• Reduce FOG entering pond by appropriate upstream treatment • Operate at positive pressure, so that cover not often in contact with water surface • Select correct cover type- HDPE has been used on most recent projects, as it is the most resistant to FOG attack
Reduce potential for physical damage to cover	• Fence around perimeter of pond • Minimise the number of fixtures on the cover • For weighing of cover for wind resistance, use fittings that are not likely to cause damage to cover eg water filled poly pipe, rather than small diameter metal wires
Reduce potential for physical stresses to the cover	• Reduce the number and weight of fixtures on the cover eg gas connection ports should be supported, rather than only supported by the weight of the cover • Set a maximum height for the cover above the water to minimise stretching of cover, look at how this can vary with season (ie higher in summer when cover warmer, lower in windy season)
Reduce ingress of non-degradable particulates (suspended solids)	• Reduce ingress by appropriate upstream treatment, particularly of green stream from stockyards/ paunch processing • Design for periodic sludge removal
Compaction of sludge and settled solids	• Consider more frequent removals of smaller volumes of solids • Look at using pipework for influent as well as sludge removal, to prevent pipes blocking • Ensure pipework is suspended off the lagoon floor
Reduce potential for venting from pond	• Design and operation of flaring system – ensure sufficient physical separation distance from pond for safety but rapid responding control system, so that biogas is flared rather than vented. • Consider installing flammable gas detectors around pond to indicate when venting is occurring, correlate to process conditions
Hydrogen sulphide and other traces in biogas are corrosive	• Given the highly corrosive nature of the condensate from the biogas (and the residual H_2S, NH_3 and other trace gases), ensure that all lines are self-draining either back to the pond so to a drop pot, to prevent pooling on low spots in the system • Consider material selection of fittings and pipework, to be suitable for prolonged contact with acid gas (ie stainless steel) • Incorporate non-destructive testing to check for integrity of pipework in critical locations as part of shutdown • If using residual treated biogas, ensure that temperatures of post-combustion gases remain above dew point of acid gases to prevent condensation and corrosion in ductwork. This would include biogas hot water heater. • Given corrosive nature of gas, ensure that entire system is designed with double block and bleed arrangement for all valving • Consider including flammable gas detection in process area around gas train
Pond cover attachment	• Consider designing pond cover so that attachment / concrete plinths holding down cover have anchor points to allow for easy removal without dragging over cover surface

3.4.2 Cover Design

The design of the cover needs to meet several criteria, including:

- secure anchorage;
- biogas collection;
- an ability to remove stormwater from the surface; and
- consideration of method of removal of scum and sludge.

The pond cover is usually anchored by burying it in a perimeter trench or anchoring to a concrete kerb. Discussion with some manufactures has indicated that in some cases, covers secured by trenches have pulled out under pressure from the biogas and/or wind.

The preferred method of secure anchorage was one area of investigation where intellectual property issues were encountered and only the “general” method of trench or concrete beam could be determined.

3.5 Biogas Handling and Collection System

3.5.1 Biogas Collection

Different biogas collection systems have been used in Australia so far, and each has advantages and disadvantages. The type will also depend on whether the gas system operates at positive or negative pressure. If the system operates at negative pressure, there will effectively be no build-up of gas pressure and the cover will be on or very close to the water level surface at all times. Negative pressure systems have the potential to draw air into the system if there are any leaks or imperfections in the system, possibly creating a flammable gas mix. If the pond operates at positive pressure, allowing the pressure under the cover to build up as gas generates (and effectively acting as a gas storage device), then air ingress is less likely, rather it will be likely that any loss of integrity in the covering system will be evident due to the smell of biogas. Most of the existing systems in the meat industry are positive pressure (A J Bush Riverstone, A J Bush Beaudesert, Camilleri).

Table 3.8 – Biogas collection

Pipe Location	Site	Advantage	Disadvantage
Across pond, under cover	Churchill	Covers whole pond area	• Prone to fouling by any floating material • Prone to submersion
Around perimeter	AJBush Riverstone, Camilleri (own design)	• Covers whole pond area • Out of way of floating layer	
Attached to pond cover	Camilleri (AGL), AJ Bush Beaudesert	Covers whole pond area	• Prone to wear and tear, leading to tear at connection points

The advantage of biogas is that it will move from an area of higher to lower pressure, so if the design includes an extraction fan (even in the case of a positive pressure system) then it is possible to capture gas without requiring a vast number of gas take off points.

An important consideration is the design of the pond outlet – it should create a water seal, like the S-bend in a toilet, to prevent gas escaping when the pressure builds up under the cover.

The cover may need vents to ensure that pressure can release without causing a rupture in the cover, however, the recent A J Bush Riverstone project, which was a positive pressure system, did not include vents, but instead overpressure was managed by the flare. If the pond is relatively narrow, the collection system around the perimeter may suffice.

An important element of the overall system is how rainwater collection on the cover is managed. A combination of positive pressure (which leads to the cover being elevated off the water level) and water-filled PVC pipes across the cover top in parallel rows has been used by Camilleri to manage rainwater, so that it pools along the sides of the cover. AJ Bush Riverstone have installed a submersible pump on the pond cover, about 5 m from the side, between two water filled 250-300 mm pipes that run along the middle of the pond cover. The pump is situated in between the weighting pipes.

Figure 8 is an aerial image of the A J Bush Riverstone plant, showing, biogas collection pipes (ridge around pond perimeter), access points (bottom left near water and black dot on top right), and 2 x 250-300mm ballast pipe along middle of pond. The stormwater pump is about 5m from right, where slight bulge between pipes exists.

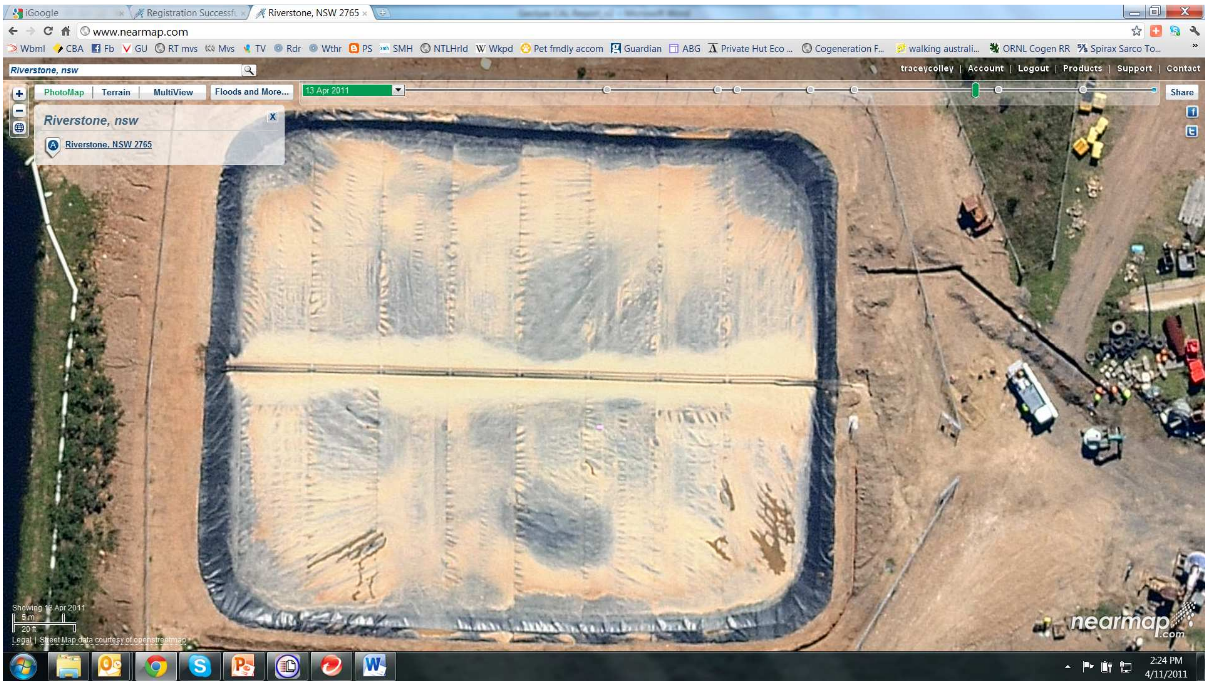


Figure 8: A J Bush Riverstone plant (April 2011)

3.5.2 Biogas Quality

Biogas produced by anaerobic digestion is likely to have a composition which is mostly methane (52-95%), with carbon dioxide (10-50%), oxygen (0.02-6.5%), nitrogen, ammonia, hydrogen sulphide and other volatile organic gases. The exact composition will depend on the feed material. The amino acids in proteins contain sulphur and nitrogen, so the more blood and meat that ends up in the wastewater system, the more sulphur and nitrogen. Tallow is purely fat (carbon, hydrogen and oxygen), so does not contain any protein but when it has come into contact with proteins in the rendering plant at temperature, then there may be some contamination with amino acids. This has been a problem in biodiesel derived from beef tallow, it is assumed that the same would hold for sheep fat/tallow.

Table 3.9 – Biogas quality

	Content % (v/v)[1]	Burrangong[2]	Southern Meats[3]	Southern Meats[3]
Methane	52-95	62-63	62	64.4
Carbon dioxide	10-50		22.8	23.2
Hydrogen Sulphide	0.0001-2	Up to 8*	15.2% for other	12.4% for other
Hydrogen	0.01-2			
Nitrogen	0.1-4			
Oxygen	002-6.5			
Argon	0.001			
Carbon Monoxide	0.001-2			
Ammonia	Trace			
Organics	trace			

Notes - * the Burrangong plant included a caustic hydrolyser to process woollen pieces for further rendering including heads, hocks, belly wool and no commercial value (NCV) skins**. It is expected that this is where the elevated sulphur levels came from, as wool is high in sulphur**.

Source: 1 – Wheatley, 1990, 2 – Mayoh, 2011, 3 – UNSW, 1998

3.5.3 Biogas Quantity

The amount of biogas generated in an anaerobic pond depends on the organic loading and the percentage of breakdown that occurs in the pond. The theoretical yield of methane from an anaerobic pond is 0.35 m^3 per kg of COD removed, although the actual yield may be lower. Assuming biogas is 70% methane, this equates to 0.5 m^3 of biogas per kg of COD removed.

The Southern Meat study found that 0.21 m^3 biogas was generated per kg COD removed and that is contained 65% methane, which equates to 0.14 m^3 methane per kg of COD removed. This was based on 6,375 mg/L COD and 87% COD removal.

In terms of methane generation rates based on current National Greenhouse and Energy Reporting Scheme default, if we assume that 80% of the COD entering the pond breaks down anaerobically and the COD entering the pond is 6,100 mg/L, and 13.7 kL/tHSCW wastewater generation rates, then:

tCH_4 = Production (tHSCW) x 0.01687
GJ methane = t HSCW x 0.867

If any of the values are different (such as quantity or quality of wastewater generated) then the amount of methane generated will vary accordingly.

For the TFI system based on a design flow of 3.14 ML/day; inflow COD of 6,900 mg/L and 80% COD removal, the CAL could produce approximately 8,670 m^3/day of biogas or 6,070 m^3/day of methane.

For an inflow COD of 3,000 mg/L this reduces to approximately 4,700 m^3/day of biogas or 3,300 m^3/day of methane.

3.5.4 Biogas Treatment

The amount of biogas treatment will depend on the quality and what it is being used for. If the biogas is simply being flared, then it will only need to remove condensate, so a system with drop pots and the pipework sloping back to a drop pot to ensure natural drainage.

If the biogas is to be used in a boiler or generating set, then as a minimum it will require:

1. Removal of condensate, by decreasing the temperature of the gas stream to precipitate out water; and

2. Removal of impurities such as hydrogen sulphide.

Hydrogen sulphide, water, alcohols and carbon dioxide act differently to hydrocarbons because of their polarity. Hydrogen sulphide is only slightly soluble in water and if it exits the biogas treatment system via a water stream, it will still need to end up going through the wastewater treatment system somewhere. There are a range of gas sweetening processes to remove hydrogen sulphide and carbon dioxide. These include chemical absorption (using amines or carbonates), physical absorption (using liquid solvents, such as refrigerated methanol or glycol), fixed beds (such as molecular sieve, iron sponge, zinc oxide), cryogenic separation, membranes, extractive distillation or fixation using biological or chemical methods. Given the scale of the operation, most of these options will add significantly to the cost and complexity and it may be simpler to exclude high sulphur streams, such as hydrolysed wool, from entering the system. TFI do not currently have a hydrolyser installed and have solids separation included as pre-treatment of effluent.

A thorough review of biogas purification processes was conducted in 2008, including systems at research and development stage (Abatzolgou and Boivin, 2008) as indicated in the following table. The H_2SPLUS system is being used in about 30 systems in the USA, including slaughterhouses. These solutions indicate that a range of techniques are available.

Table 3.10 – Commercially available biogas purification solutions

Companies	Elements	Characteristics	Applications	Other Data
Schmack – Biogas AGCarboTech Process	1. Compression 2. Dehumidification 3. Desulfurization 4. Decarbonisation 5. Siloxane removal	1. Up to 5 bars 2. By moderate quenching 3. Fixed-bed catalytic adsorption on AC 4. PSA adsorption on molecular sieves 5. Same as Point 4 They do not give costs but claim that the overall specific costs for gas purification are very weak (unclear…)	Not specified Unlimited	− Capacities between 500 and 5000 Nm^3/h − They sell a 'Zero emission technology' option (ZETECH4®); it seems that they recycle the separated CO_2 back to the CH_4 production step (unclear…)

Table 3.10 – Commercially available biogas purification solutions

Companies	Elements	Characteristics	Applications	Other Data
Eco-Tec Inc. BgPur™ BioGas Purifi cation System	Removal of H_2S and particulate matter by liquid scrubbing	− 99%+ H_2S removal − Automatic adjustment for H_2S and flow levels − Small, skid-mounted, pre-assembled, pretested, easy-to-install and operate − Capacity according to specific needs	Municipal WWT − Industrial WWT − Food and beverage processing − Meat rendering − Landfill gas − Pulp and paper mills − Agri/livestock farms	The adsorbing solution contains NaOH and a proprietary chemical additive (Eco-BGA-1solution); pH around 8. The absorbing solution is regenerated using O_2 to oxidize S^{2-} to S^0; the solution is then re-used. NaOH is consumed as a make-up.
Guild Associates, Inc. Guild PSA Technology	1. Compression: 4–7 atm 2. The Guild PSA system removes water, CO_2, and H_2S to meet pipeline specifications. 3. The tail gas can be used as local fuel or flared, as necessary, since it has a relatively low heating value	The system: removes water to pipeline specifications of less than 0.11g/Nm^3; removes H_2S to a typical requirement of 4 ppm; and removes CO_2 as required by pipeline specifications (typically in the range of 1 to 3%vol).	No limitations reported	
Shell-Paques/ Thiopack™ Technology	H_2S removal with bioscrubber	Alkaline absorption H_2S $+ OH^- \rightarrow HS^- + H_2O$ followed by biological oxidation in a liquid phase bioreactor $HS^- + ½ O_2 \rightarrow S^0 + OH^-$ – pH=8–9	– High-scale system – Oil industry – Wastewater plant	– Flow between 500 and 2500 Nm^3/h – Economical for removal capacity higher than 50 tons S/day
MVLLC Inc. H_2S PLUS™ Technology	Iron sponge with thiobacteria – Chemical and biological H_2S removal	– Heated vessel with nutrient recycle loop – S oxidizes to S^0 – 1/3 of S^0 is produced by the biological pathway	Agrifood processing factories (slaughter houses, potato factories, alcohol plants)	– Flow between 17 and 4200 m^3/h – 225 kg of H_2S per day – US$2.20 per kg of S removed. – Capital investment for1700 m^3/h of biogas containing 5000 ppmv H_2S is US$450 000

Trickling bio-filters have been suggested as a low cost, low complexity and robust technology for removing ammonia and hydrogen sulphide from water streams. The H2SPLUS system needs to have the bed changed about every 6 months, and the spent bed material can be used as fertiliser.

In Europe, the majority of applications are on-farm digesters. There, farmers maintain 4-6% air in the bioreactor headspace, so that H_2S oxidises to sulphur, and the air concentration limit is controlled so that it does not reach the lower explosive limit. It is unlikely that this system could be implemented on a large CAL, due to the difficultly in controlling the air concentration underneath the whole cover.

3.5.5 Flaring and Venting

A comprehensive assessment of Australian Biogas Flaring Standards was undertaken by RIRDC in 2008. A flare is an essential part of any biogas system, as the biogas contains methane. There are 2 types of flares – open or enclosed. As the names suggest, open flares have a flame which is visible from a distance, whereas enclosed flares do not have a flame that is visible from a distance. Enclosed flares cost 1.5-2 times the amount of open flares, but it is probably worth it in terms of being less likely to cause community concerns and complaints from neighbours.

Flare systems generally include a knock-out pot (to remove liquids), a flow control system, a fan or gas booster (to achieve the required pressure for reliable combustion), a shutoff/safety system, a flame arrestor and the flare itself. The flare would generally involve monitoring and metering equipment, such as flowrate, pressure and a flame sensor. The system may also include a pilot gas system, which is designed to ensure reliable combustion where the gas quality or flowrate varies.

Flares would normally need to be included as a new emission source in any existing environmental licence for the site. They may have special approval requirements from the local council, but this would generally be included in the overall approval for the wastewater project.

Biogas collection and use is covered by a number of safety requirements. Each state or territory will have requirements relating to gas safety and the level of regulation may vary depending on whether the flare has a LPG pilot or not. As a minimum, the gas collection/treatment system, including the flare, would be expected to comply with the relevant Australian Standards which are:

- AS3814/AG501 for Industrial and Commercial Gas-fired Appliances (for flares using LPG Pilots)
- AS1375 – Industrial Fuel Fired Appliances
- AS5601 – Installation requirements

Normally the flare manufacturer would be aware of all legislative requirements. There are a number of Australian manufacturers, namely Australian Burner Manufacturers, Aquatec Maxcon, EPCO, Energen, Gasco, GCD, LMS and Varec Biogas (RIRDC, 2008). There are overseas manufacturers of biogas flares such as John Zinc (USA), who supplies flares to the oil and gas industry.

Flares are normally designed to operate on pressure, so that if the pressure is building up under the cover, the flare will burn the biogas rather than it being released by the safety vents. If not managed properly, venting can be the source of odour from the biogas system.

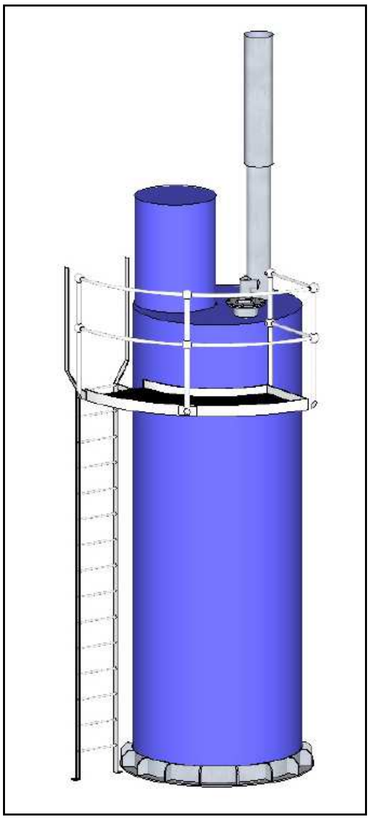


Figure 9: Australian Burner Manufacturers Biogas Water Heater

Australian Burner Manufacturers have a variation on a standard flare which includes a water heater. This can be designed to heat water to whatever set point is required and still achieve 99+% destruction of the biogas. It features an LPG pilot, a self-checking flame detection system and flame arrestor. This may be an option for recycling water to the CAL to maintain the required temperature in the reaction zone, with water from the sludge removal system.

3.6 Cost Benefit Analysis

There is insufficient data to conduct a thorough cost benefit analysis on most of the options outlined in this report, as they have never been investigated at sheep or red meat processing plants. Most of the information comes from piggeries, manure handling for intensive agriculture (such as feedlots) or from the municipal treatment industry. There is an absence of actual field data from the red meat industry. Rather than use inaccurate or estimated data and then reliance being placed on the analysis, the emphasis has been on identifying data gaps that will be met by the research to be undertaken as part of the TFI CAL project. Not all of this may be relevant to TFI given the improvements currently being made to the wastewater treatment system upstream of the CAL.

Table 3.11 – Data requirements for CBA

Project Element	Likely Benefit	Data Required to Undertake CBA
Install enhanced grit removal system on green stream (pit, screw press, hydrocyclone). 2 smaller hydrocyclones to be installed in parallel, rather than one large hydrocyclone, to improve reliability and provide redundancy	• Reduce or eliminate non-biodegradable particulates from CAL influent • Understanding of root cause of upsets to hydrocyclone → develop user manual for RMI	• Water testing on influent from green stream to determine residual TSS level from non-biodegradable particulates with and without various system components • Develop target TSS for influent from green stream, with split between biodegradable and non-biodegradable (ie COD vs BOD values) • Data on reliability of dual hydrocyclone system eg % downtime, planned vs unplanned shutdowns etc
Install enhanced oil and grease (O&G) removal system on red stream (screens, DAF, hydrocyclone)	• Reduce FOG entering CAL	• Water testing on influent from red stream to determine residual O&G level with and without various system components • Develop target O&G for influent from red stream • Data on reliability of dual hydrocyclone system eg % downtime, planned vs unplanned shutdowns etc
Install mono muncher (or equivalent inline macerator) to reduce size of particulates in influent entering CAL	• Increased rate of biodegradation/biogas generation due to increased surface area	• Biogas generation rates with and without use of macerator • Distribution of particle sizes with and without macerator
Use of biogas water heater instead of basic biogas flare	• Maintaining water temperature in CAL in optimum temperature range for mesophilic bacteria → increased rate of biodegradation • Beneficial use of biogas when plant not operating, rather than venting from pond cover	• Biogas generation rates with and without use of biogas water heater • Estimate of reduction in venting, based on pressure readings from pond, and resulting greenhouse savings
Installation of pipes on bottom of pond, with manifold so can be used for influent /feed or sludge recycling. Needs to include automated TSS solids detection system on outlet of CAL & trial of influent being fed into different zones of pond. Also consider installing pipes with different sizing/ location of holes, to determine most effective pattern eg holes becoming gradually larger the further away from pump they are	• Increased rate of biodegradation/ biogas generation due to better mixing of influent with active sludge • Reduced likelihood of blocking of sludge removal pipes • Ultimate aim to develop rule of thumb and convert system to largely automated system • Larger effective pond volume, less likely to wash out bacteria • Assist with making temperature uniform throughout pond through setting up vertical currents, may be beneficial in summer when high temperatures under cover may kill bacteria	• Trials of various sludge recycling regimes, to determine optimum balance between recycling and wasting. • Biogas generation rates for different regimes • Operating costs (electricity, labour etc)
	AND/OR	

Table 3.11 – Data requirements for CBA

Project Element	Likely Benefit	Data Required to Undertake CBA
Installation of access ports on cover in second half of pond, for trial of periodic removal of sludge using sludge rate. Will need to be programmed to run between sludge pipes, or may be alternative to sludge pipes.	• Solids removal without having to remove cover • Increase in effective pond volume, leading to increase in residence time and increase in treatment in anaerobic pond, and increase in biogas generation	• Trial of different types of sludge removal equipment eg volume removed, solids removed • Biogas generation rates for different regimes • Operating costs (electricity, labour etc)
CAL influent/ effluent composition vs biogas composition	• Understanding of mass balance ie what ends up leaving the system with the biogas and what stays in the water. This is particularly relevant for sulphur and nitrogen, as certain types of nitrogen (eg urea) may end up leaving as ammonia in the biogas, rather than with the water (where it has beneficial reuse potential)	• Influent and effluent water quality, biogas composition → mass balance • Refer to ISO 11734:1998-11/ ISO 11734:1995 and ISO13641:2003
Nitrogen control on final effluent (if loadings are a problem). Recycle small stream from aerobic part of system, to determine whether anaerobic/aerobic/ anaerobic treatment increases	• May be difficult to achieve given distance from aerobic ponds to anaerobic pond • Water recycling on weekends/ when flow from plant is minimal/ not operating • Consider heating water to maintain pond temperature at optimum	
Flammable gas detectors around pond, linked to alarm and flare system	• Determine what causes venting from pond → may relate to influent, biogas generation rate, pond temperature, flare system control etc	• Look at variety of parameters (pond temperature, biogas composition, etc) to determine when increase in pressure occurs and why flare system does not manage

3.7 Monitoring

The amount of testing required on biogas production from the CAL will require installation of additional monitoring and metering equipment, including the ability to record and track data over time, rather than the more simple control system which would normally be installed. Ideally, the data would be linked back to a control system, so that the various parameters can be tracked over time and the data exported to enable analysis. The exact type of monitoring equipment should also give consideration to the requirements of the National Greenhouse and Energy Reporting system, to ensure that adequate data is collected. As not all these parameters can be monitored online, consideration should be given to installing an automatic sampler to reduce labour costs. JBSwift Longford have an automatic sampler on their wastewater to trade waste, a Hach Sigma autosampler. Refer to RIRDC 2010 report on Bears Lagoon for details on monitoring.

Table 3.12 – Monitoring requirements (ideal)

Stream	Parameters to be Monitored
Influent water to CAL	Temperature, pH, TDS, total solids, dissolved oxygen (DO), volatile fatty acids (VFA), alkalinity, COD, sulphide, O&G, TKN, TP, volatile solids
Influent flows	Monitoring of where flows are directed eg flow monitors in pipes into pond floor
Effluent from CAL	Temperature, pH, TDS, TSS, DO, VFA, alkalinity, COD, sulphide, O&G, TN, TP
Biogas generation	Pressure, temperature, flow rate, methane content, H_2S content, ammonia content, carbon dioxide content

It may be worthwhile tracking biogas production and how it correlates to temperature, and if needs be, introducing a heated recycle stream, particularly on weekends when the plant is not generating any wastewater. This could use heat rejection from the ammonia refrigeration system, which is operational when the boilers are not.

3.8 Design Recommendations from Desk Top Review

A HRAL system is the preferred CAL system for the TFI abattoir as it will minimise the footprint of the CAL and it incorporates design features of sludge recycling/mixing. The UNSW CRC for Waste Management & Pollution Control (1998) state that a high rate process can result in a threefold increase in treatment efficiency and that a construction cost analysis showed the high rate systems are 65% to 78% of the cost for a traditional lagoon.

The conceptual CAL for the TFI site was based on a lagoon volume of 60 ML. Doubling the loading rate for the system by moving it to a high rate system would reduce the volume to 30 ML. A high level cost analysis of the major components (earthworks, liner and cover) is presented in Table 3.13 which shows a substantial reduction in the major cost components can be achieved.

Table 3.13 – Indicative major component capital costs

Component	Indicative Rate	60 ML CAL		30 ML CAL	
		Quantity	Cost	Quantity	Cost
Earthworks	$15/m^3	39,000 m^3	585,000	24,000 m^3	360,000
Liner	$10/m^2	16,200 m^2	162,000	12,220 m^2	122,200
Cover	$22/m^2	13,200 m^2	290,400	11,000 m^2	242,000
Total			**$1,037,400**		**$724,200**

There are a number of design decisions that need to be made which are summarised in Table 3.14.

Table 3.14 – Design considerations

Design Element	Consideration
Pond cover life	If the cover system is designed for a 10 year life, then sludge removal considerations are less important and the anchoring system does not need to allow for removal and reinstatement.
Pond operation	It seems that a positive pressure system is the current preferred model, rather than a negative pressure system.
Type of pond	A HRAL, where the feed can be fed through a normal feed location or via pipework on the pond floor at the front end of the pond allows for operational flexibility. The same pipework could also be used for sludge removal. If this pipework is included, then TFI could work with AMPC/MLA to research pond optimisation (including other issues such as sludge removal and recycling). If something happened to the pipework on the floor of the pond, then the traditional inlet could still be used.
Sludge removal	Ideally, small amounts on a more frequent basis are preferred to larger, less frequent amounts

There are several areas of CAL design where various manufacturers, suppliers and/or installers are reluctant to divulge information due to intellectual property issues. These include:

- Cover systems and anchorage;
- Effective biogas collection systems; and
- Sludge/effluent recycling.

Much of the information has been gathered from practical experience during construction and development of CAL systems. While some generic information can be obtained, the design details will not be released for public exhibition.

For this project, and to avoid having to design the CAL from first principles, it was determined that the best approach was to specify a design and construct tender.

4 CAL Design

4.1 Process

The design of the CAL system at TFI was a co-ordinated effort between different companies and engineering disciplines. The CAL design process included:

1. A desktop review of CAL design options (presented in Section 3 of this report);
2. Field studies and inspection of various CALs constructed throughout the eastern states of Australia;
3. Development of a concept design;
4. Calling for design and construction tenders for the CAL;
5. Tender review and tender award;
6. Design review and amendments; and
7. Detailed design and construction.

Detailed design was carried out in conjunction with construction. This was an interactive process between designers and construction staff. This ensured construction was as easy and cost effective as possible whilst still meeting the design requirements of TFI.

During the project cycle, from inception to concept design and through to detailed design, there were various issues requiring design changes to ensure the requirements of TFI were met whilst not compromising the technical feasibility of the CAL.

4.2 Site Specific Preferences

Following the desktop review of CALs and inspection of various existing CALs a concept design was developed based on the following TFI preferences:

- A twin CAL design, as this would offer redundancy in the event that one pond failed or required maintenance;
- No rain water is to pool on the CAL cover, this important aspect was often overlooked at other CALs and as well as adversely impacting the visual aesthetics of the CAL it can also add unnecessary load and stress to the cover;
- The roads surrounding the CALs are to drain away from the CAL cover. This would ensure adequate cross drainage of access roads, ensure no stormwater runoff would flow onto the cover and act positively on the CAL visual amenity;
- The bio-gas flare is to be high temperature (900-1200℃). In this case a high temperature flare was the best option as maximum methane destruction is achieved; and
- Operational flexibility of the influent, effluent and sludge removal/distribution system. In the case of TFI it has been a simple design task with minimal extra cost to build operational flexibility into the effluent distribution system. CALs are a relatively new technology so the design philosophy has been to incorporate operational flexibility. The additional infrastructure required to increase the operational flexibility was minimal.

4.3 Concept design

A review of CAL design options was carried out and a subsequent CAL design recommendations report prepared. The CAL design recommendations report highlighted the fact that while there was available information on the general operational philosophy and objectives of a CAL, there was a lack of readily available detailed CAL design information. There were numerous companies with the ability to design a CAL, however all companies indicated that the information was proprietary knowledge. Detail around CAL design is held and somewhat protected by experienced industry professionals and for this reason the contractual approach of a Design and Construct (D&C) contract was taken. By using the D&C approach TFI were able to utilise the protected knowledge within the CAL industry.

Using the CAL design recommendations report as a basis, an all-encompassing concept design was developed. This approach enabled all companies to offer a tender based on the same design which simplified the tender evaluation process.

The concept design incorporated the following features:

- Twin CALs with options for operational flexibility;
- High Density Polyethylene (HDPE) lining of the internal batters and floor to prevent leakage and groundwater contamination;
- A leak detection system underneath the pond liner;
- HDPE floating cover for biogas collection;
- Provision for stormwater removal from the HDPE cover;
- Provision for sludge recycling and removal from the CAL;
- Gas collection and processing system including high temperature flare; and

- Controls and monitoring to measure effluent flows and biogas generation.

4.4 Tendering Process

There were three separate tenders to facilitate the construction of the CALs:

1. The lagoons bulk earthworks tender;
2. The CAL D&C tender; and
3. Transfer pump D&C tender.

The two separate tender packages were developed for the CALs as it was recognised that the bulk earthworks to construct the lagoons would need to commence well before lining of the CAL's and the likely scenario that CAL design contractors would not necessarily have the capacity to undertake bulk earthworks.

4.4.1 Bulk Earthworks Tender

The bulk earthworks tender required geo-technical investigation, assessment and development of an embankment compaction specification, development of a balanced three dimensional earthworks model and the calling of, assessment of and award of the tender.

4.4.2 CAL Tender

The CAL D&C tender involved a desktop review of CAL technology, development of a concept design, tender assessment and award of the tender.

The CAL tender was based on a D&C contract that had the following critical minimum performance specifications:

- Pond size – required minimum 80% Biochemical Oxygen Demand (BOD) reduction with the final pond design to be determined by the D&C contractor;
- The design must ensure the build-up of struvite in the system is minimised;
- The effluent distribution and sludge collection system must be designed to minimise the quantity of automated valves;
- The gas collection system and all associated gas collection components will conform with the relevant Australian Standards;
- CAL covers to include stormwater removal and textured walkways to allow access to rainwater sumps;
- CAL covers to be tested to 60 Pa; and
- All control systems will be ethernet based.

The tender included the need to successfully commission the CALs.

4.4.3 Transfer Pump

A new pump system was required to transfer effluent from the CALs to the Pahl Farm.

A D&C tender was developed for the design and construction of the pump station and associated balance tank for this purpose.

4.5 CAL Tender Assessment

A closed tender was let to five companies to provide design and construction services for the CAL. Companies were invited to tender on a concept design which included a twin CALs. The CAL conceptual design was included so that all companies could offer a tender based on the same design which simplified the tender evaluation.

Three companies responded with a formal tender. For the purposes of this report, no details will be provided on the tenderers or their tender price, and the companies will be referred to as Companies A, B and C.

Weighted evaluation criteria were adopted for the tender evaluation. All tenderers were informed of the evaluation criteria in the CAL D&C tender documents. The evaluation criteria were:

- Price;
- Technical merits of system proposed;
- Company capability to provide full design and construct services;
- Relevant company experience; and
- Ability to meet timeframes.

Each company was scored from 1 to 5, with 5 being the best score possible. Results of the evaluation process are summarised in Table 4.1.

Table 4.1 – CAL tender evaluation scores

Criteria	Weighting	Company A	Company B	Company C
Price	50%	2	3.5	4.5
Technical Merits of proposed system	20%	3	4	4
Company Capability	7.5%	4	4	4
Relevant Experience	7.5%	4	3	4
Ability to meet time frames	10%	3	3	3
TOTAL	100%	7.9/11.5	8.9/11.5	9.4/11.5

The tender evaluation process revealed two preferred contractors (Companies B and C) and discussion were undertaken with each company to clarify aspects of the project and submissions.

As a result of the tender clarification meetings and design revision the concept design was revised to adopt the following changes:

- Internal batter slopes changed from 1:3 to 1:2.5; and
- A high temperature biogas flare was reinforced to be the specified flare.

Both parties were asked to submit a revised fee proposal on the above changes for consideration. Following the submission of tender revisions, Company C emerged as the preferred contractor and was awarded the contract. The final contract was based on a twin 20 ML CAL design.

4.6 Design Review

Post tender award the contractor was required to host a design review meeting where the proposed CAL design was presented for review. The review outlined areas where the proposed design differed from the concept design.

The proposed design by the contractor stated that for the predicted loadings twin 20 ML CALs would be required. A twin 20 ML system would provide the required hydraulic retention time and ensure an 80% BOD reduction could be achieved. The resulting organic loading for the system is summarised in Table 4.2. These are based on:

- Design flow of 3.14 ML/day (22 ML/week averaged over 7 days);
- Inflow COD of 6,900 mg/L
- Inflow BOD of 5,100 mg/L

Table 4.2 – Organic loading rates

Measure	2 x 20 ML CALs
COD: kg/m^3/day	0.54
BOD: kg/m^3/day	0.40
Hydraulic residence time, days	13

Other design changes have been ongoing throughout the evolution of the project; the ultimate design of the CALs is described in later sections.

4.7 Final CAL Design

A CAL is a covered pond/lagoon that facilitates an environment where anaerobic bacteria thrive, reproduce and effectively digest waste water. The main components that make up a CAL are:

- the lagoon;
- the lagoon liner;
- the lagoon cover and gas collection train; and
- the effluent distribution system.

4.7.1 The Lagoon

Design of the lagoons involves careful consideration of the lagoon size and also involves a civil earthworks design element. Construction of the lagoons involves bulk earthworks to create an empty and unlined lagoon. The lagoon component of the CAL excludes all auxiliary CAL components.

CAL Sizing

Following a desktop review and consistent with the preference for a twin CAL system a concept design for twin CALs was developed, this concept design accompanied the D&C tender. Following award of the D&C tender the concept design was reviewed and subsequently a twin 20 ML CAL system was adopted.

The combined capacity of the CALs provided a total of 40 ML. This provided a slight factor of safety which would ensure the CALs could operate effectively under all probable effluent loading scenarios.

The CAL size also considered the downstream facultative system at the Pahl Farm. It was considered a better option to increase the CAL volume as a method to eliminate COD rather than attempting to eliminate excess COD at the Pahl farm ponds.

Civil Design

Following CAL size confirmation of twin 20 ML ponds, a three dimensional earthworks model was developed. The objective of the three dimensional earthworks model was to balance earthworks between the material excavated and the material required to build the ponds (a balanced cut and fill model).

The design model incorporated the fill required to construct a landscaping screening bund. The landscaping bund effectively eliminated the visibility of the CAL's from neighbouring residential houses.

The two ponds were aligned and adjusted to fit the site. The resulting length to width ratio was approximately 2:1.

Final dimensions of each CAL are:

- Length (at operating water level) 101.2 m
- Width (at operating water level) 52.6 m
- Maximum depth 6.7 m
- Freeboard 0.9 m

4.7.2 The Lagoon Liner

The lagoon liner is the impermeable membrane which is fixed to the inside surface of a lagoon and acts to provide an impervious layer to contain effluent to within the lagoon. An impervious lagoon liner helps ensure no effluent can leak and contaminate any ground or surface water. Lagoon liners can be constructed from naturally occurring materials, such as high plasticity clay or a synthetic material such as a HDPE membrane.

The ability to construct a liner from naturally occurring materials depends on the presence of suitable materials. Suitable materials are typically highly plastic clays as this tends to have a very low permeability (a low hydraulic conductivity).

At the TFI location there was no material suitable to construct a clay liner, so a synthetic liner was selected. The lining material chosen was 1.5 mm HDPE liner.

During the design phase it was determined that a larger lagoon volume could be obtained by steepening the internal batter slopes of the lagoon. Original design parameters included internal batters of 3:1 (H:V). Internal batter slopes of 2:1 would have been technically feasible, however due to safety and constructability concerns raised by the liner installation contractor, 2:1 internal batter slopes were deemed to be too steep. Subsequently the internal batters were changed to be 2.5:1 which achieved a compromise between lagoon volume optimisation and ease of construction.

4.7.3 The Lagoon Cover

A 2 mm HDPE synthetic cover was designed for the CAL's. There are three main functions of the CAL cover, these are:

- eliminate odour;
- capture bio gas; and
- prevent rain water from entering the CAL.

Biogas Collection

The anaerobic digestion process is well documented and throughout the later stages of digestion methane and carbon dioxide are produced. For this reason a cover is installed over the lagoon to contain odour and capture the gases. Once the gases have been captured, it is then typically piped to a high temperature flare where it is burnt to atmosphere or burnt to generate electricity.

The biogas collection system at the Murray Bridge CAL's was designed by Quantum Power Ltd using the MegaFlo 3000 drainage cell (Figure 10). The MegaFlo drainage cell system is comprised of a perforated ring main installed around the internal perimeter of the CAL, between the CAL liner and CAL cover. The gasses trapped in the Megaflo ring main are connected to a single extraction point in each CAL. From this point the biogas is piped to a biogas flare and destroyed through burning.

An automatic vent system to relive pressure under the cover was designed to open when the pressure under the cover exceeds 50 Pa. The vent is a weighted disc on a 150 mm pipe with a stainless steel shroud. It is opened by pressure and requires no power to operate.

Figure 10: MegaFlo gas collection pipe

Rainwater Collection

The rainwater collection system has been designed with the philosophy of strategically placing weighted pipes on the CAL cover that direct rainwater to a central rain water sump. The weight system designed was comprised of 200 mm water filled HDPE pipes installed in a “rib cage pattern”. There are two centre pipes running longitudinally along the cover with side pipes installed perpendicular to the centre pipe.

The original design incorporated a rainwater sump pump that would pump out rainwater and discharge it beyond the southern CAL batter slope. The sump pump is required to be intrinsically safe because of the close proximity of the pump to flammable methane gases. It was not possible to source a pump that would be intrinsically safe in atmosphere (as opposed to being submerged). Subsequently the design was altered to incorporate a gravity transfer pipe from the rainwater sump, under the CAL cover through the southern embankment to discharge beyond the southern batter slope. The conceptual design of this system is shown in Figure 11.

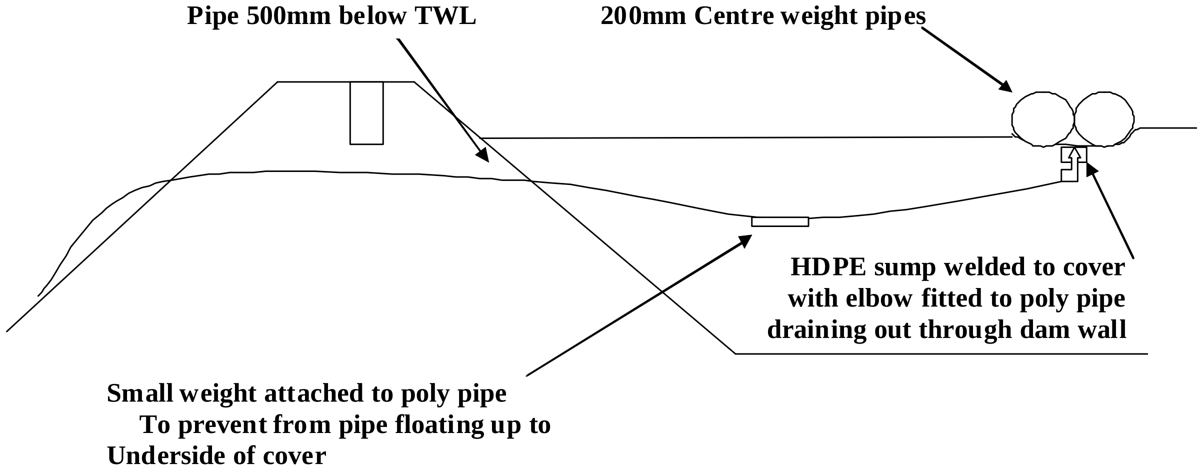


Figure 11: Rainwater Collection system

The advantages of the rainwater collection system are:

- no pump or electrical systems are needed and the system is therefore intrinsically safe; and
- it is a passive system with no mechanical systems which makes it essentially fail safe.

The disadvantages of the rainwater collection system are that it is:

- difficult to construct;
- there are more penetrations of the liner which adds further possible leak point through liner; and
- the pipe could silt up at the bottom loop over time and may require cleaning out, this could be difficult.

4.7.4 Effluent Distribution

The effluent distribution system includes the entire effluent handling and sludge removal system. The TFI CAL effluent distribution system is capable of the following functions:

- distribution of effluent into the each CAL;
- transfer of effluent from each CAL to the transfer pump station;
- injection of effluent into the sludge bed;
- sludge recycling; and
- sludge removal.

A schematic diagram of the effluent distribution system is shown in Figure 12.

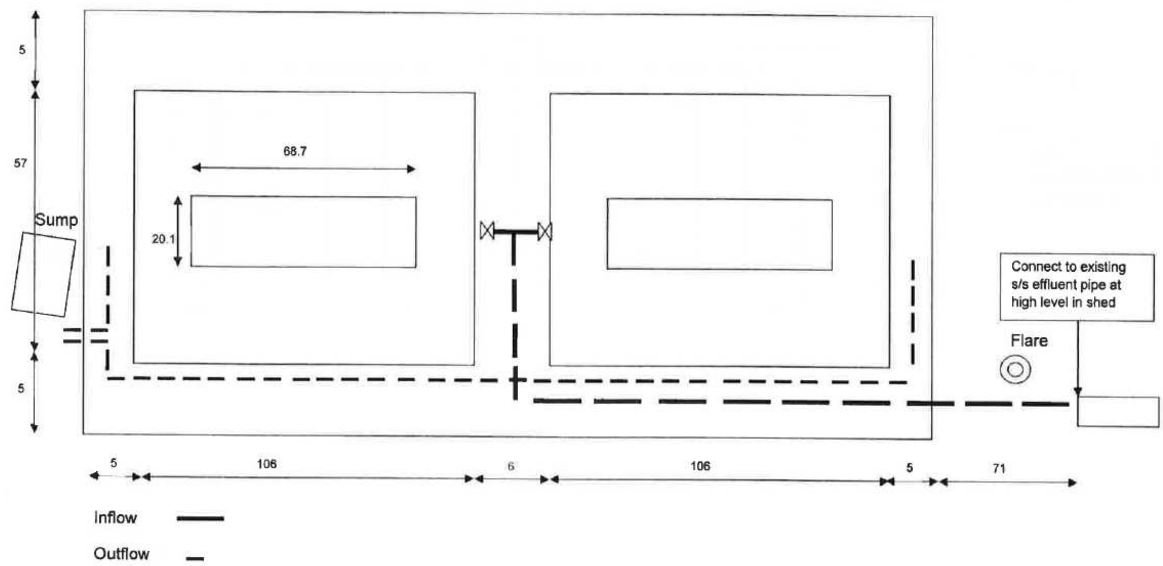


Figure 12: Effluent distribution system

Effluent is pumped from the DAF to a central inflow weir. From the central inflow weir the effluent is gravity fed to the lower depths of the CAL. Under normal operation the effluent then flows out of the CAL at the opposite end to which it entered.

Effluent flows from the top effluent level in the CAL into an outflow weir and from there to the transfer sump.

Inflow and outflow weirs were used for the following operational reasons:

- The sludge extraction system could also reintroduce the sludge into the inflow effluent stream (recycled sludge). The weir box provides a mixing chamber for this;
- The sludge system can be reversed to introduce effluent into the sludge bed. The weir box provides a sump to draw this effluent from. This could probably have been taken directly from the CAL but that would have required another penetration and is not the ideal situation;
- The inflow weir is fitted with a valve system where the effluent going into the CALs can be balanced or one isolated at a time. This is more easily done in an open weir;
- The arrangement of the outflow weir is such that the top water level of the CAL can be controlled by the height of an adjustable board in the outflow weir; and
- There is a small hatch in the weir box cover for taking effluent samples.

Another operation of the CAL effluent distribution system is sludge removal. A schematic diagram of the sludge removal system is shown in Figure 13.

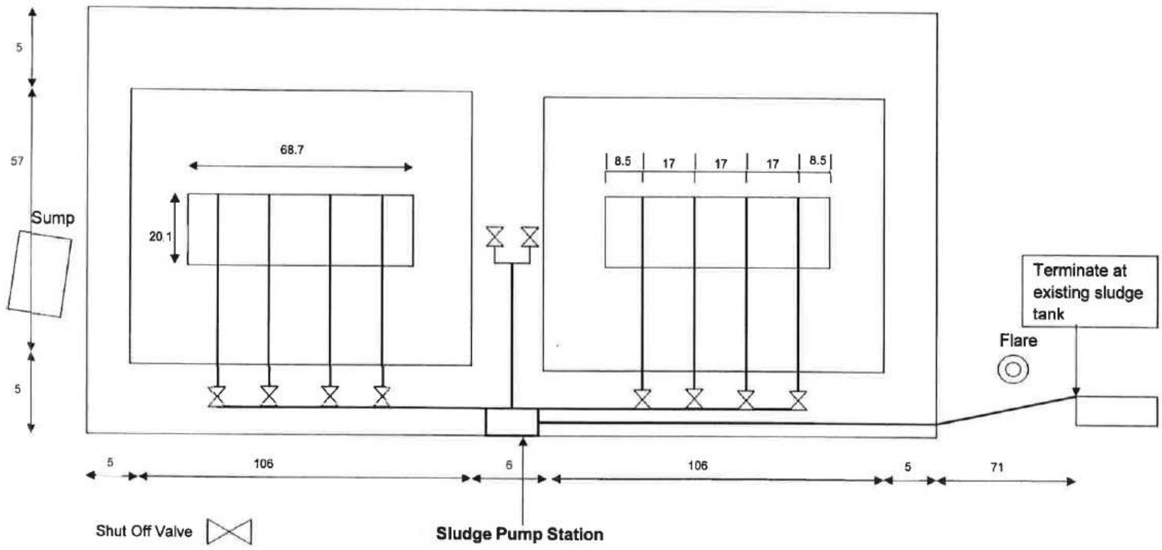


Figure 13: Sludge removal system

The sludge removal system can be manipulated to perform following operations:

- removal of sludge and pump it to the sludge tank;
- recycling of sludge by extracting sludge from any of the 4 extraction points in each CAL and pumping it to the effluent inflow weir; and
- injection of effluent into the sludge bed.

The above functions are achieved through manipulating a series of valves at the sludge pump station as shown in the schematic (Figure 14).

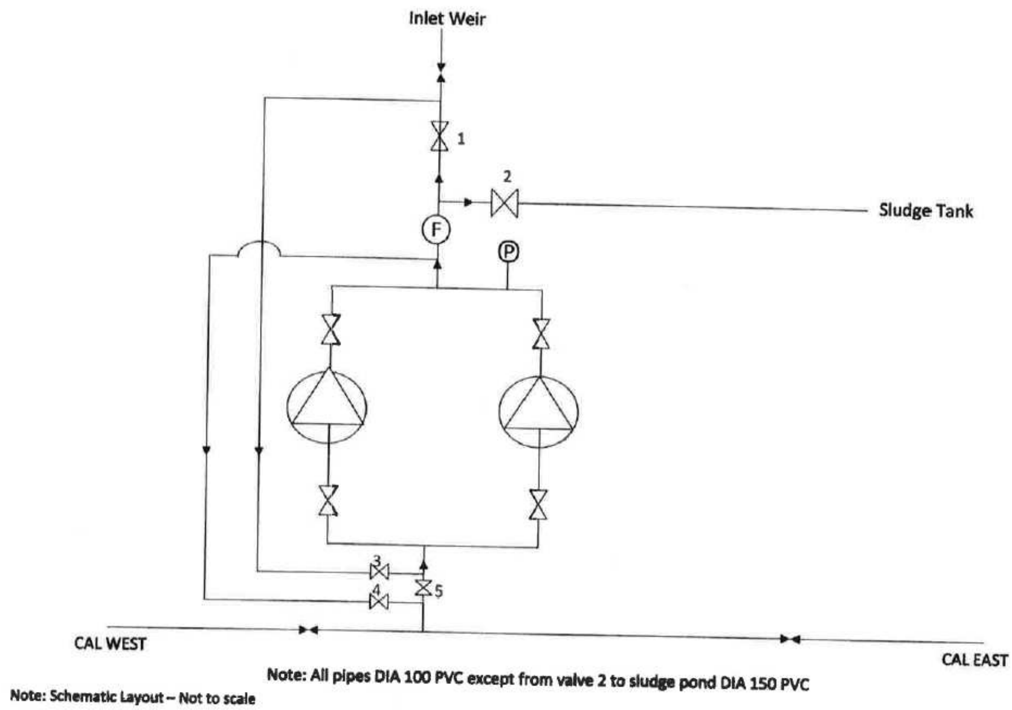


Figure 14: Sludge pump station

4.7.5 Biogas Gas Train

The final biogas train includes:

- A 100 mm diameter pipe to convey biogas from the western CAL. This increases to 150 mm at the junction with the biogas offtake from the eastern CAL;
- A knock-out pot;
- Flow meter and gas analyser;
- Blower;
- Double block and vent;
- Pressure control valve;
- Flame retarder; and
- High temperature flare.

A LPG system controls the flare pilot light.

The flare operates automatically and:

- Starts when the pressure in the CALs rises above 40 Pa; and
- Stops when pressure in the CALs falls below 20 Pa.

The gas train and high temperature flare is shown in Figure 15.

Figure 15: Installed gas train and high temperature flare

5 Construction

5.1 Overview

Construction of the twin 20 ML CAL's has been a cooperative effort between TFI, bulk earthworks contractors, civil construction contractors, liner installation contractors and electrical service design and installation contractors. This section reviews the practical implementation of the design during the constructing of the twin CAL system. Construction of the twin CAL system involved the coordinated design and construction of the following sub components:

- the lagoon;
- the lagoon liner;
- the lagoon cover and gas collection train; and
- the effluent distribution system.

Construction commenced in February 2012 with the site clearing and bulk earthworks. The first design coordination meeting was held on 21 March 2012. Practical completion was achieved on 4 October 2012. The construction period was hampered by significant wet weather events.

Commissioning of the CALs commenced on 24 September 2012, with the biogas and flare system commissioned on 26 November 2012.

5.2 Scheduling of Works

With any construction project it is important to give consideration to the scheduling of works. The schedule of construction works to construct the twin CAL system at Murray Bridge was conducted in the following order:

1. The lagoon

The bulk earthworks lagoon construction was undertaken as the first task because of the need to create the base lagoons that all auxiliary CAL components could connect to.

Bulk earthwork included installation of the leak detection system in the base of each lagoon.

2. The effluent distribution system

The effluent distribution system was required to be installed as the second priority. Before the CAL liner could be installed the location of pipe penetrations into the CAL needed to be fixed. It was practical to install the entire effluent distribution system whilst installing those components of the system which penetrated the CAL internal batter. It was not practical to install the CAL liner while the effluent distribution system was being installed. This is because the trenching required to install the effluent distribution system conflicted with the location of the liner anchor trench.

The effluent distribution was also required to be installed prior to the CAL liners as this would facilitate filling of the lagoons with effluent, which would facilitate installation of the CAL covers.

The electrical and control reticulation system was installed in the trenches with the effluent distribution system and as such this system was installed at the same time as the effluent distribution system.

3. The lagoon liner

Following installation of the effluent distribution system it was then possible to install the lagoon liner. The lagoon liner needed to be installed prior to the CAL cover as the CAL cover installation required the lagoons to be filled with effluent.

4. The lagoon cover

Following installation of the lagoon liner it was then possible to fill the lagoons and use a winch and floating pontoon method to fabricate the lagoon cover.

5. CAL to Pahl farm pump station

This pump station connects to the CAL effluent outflow pipes and pumps the post CAL effluent to the Pahl farm. It was possible to commence construction of this pump station following the installation of the effluent distribution system and as such the design and procurement process for this pump station was ongoing whilst all other components were being designed and constructed.

During the planning phases particular emphasis was placed on procuring items with long lead times as a priority. The items with the longest lead times were; the biogas flare, the liner and cover material and the pump stations.

5.3 The Lagoon

5.3.1 Design Issues and Changes

The design of the lagoon involved the development of a digital three dimensional model of the lagoons. This digital model was then provided to the earthworks construction contractor. The earthworks contractor used GPS control systems to construct the lagoons.

A preliminary digital earthworks design model was developed for construction. This preliminary model was 95% complete with the remaining component being the slope design of the lagoon floor. This approach enabled bulk earthworks to commence while the CAL design contractor finalised the lagoon floor design.

Upon confirmation of the lagoon floor design a second digital earthworks design model was issued with the required lagoon floor shape.

The construction methodology being model and GPS based proved to be somewhat troublesome. Between the preliminary design model and the final design model, the earthworks contractor found the top of bank levels differed when entered into his GPS system. The design top of bank levels did not change between design models and the discrepancy was unresolved.

The digital earthworks design model and GPS based approach resulted in the lagoon not being constructed strictly to the design. For this reason the ponds needed to be surveyed so that an as built holding volume could be determined.

The survey revealed that the as built ponds were not the required 20 ML each. This instigated two mitigation measures:

1. raising the top of bank level of the lagoons to be closer to the design level; and
2. reducing the freeboard from 1.0 m to 0.9 m.

The resulting total pond volume at the design operating level was 40 ML.

Bulk excavation of the eastern CAL is shown in Figure 16.

Figure 16: Bulk excavation of eastern CAL

5.3.2 Construction Issues

The bulk earthworks, particularly the finishing of the internal surface for liner placement was significantly impacted by rainfall. The area received more than double the annual average rainfall during the construction period.

The internal pond walls were lined with clay to provide a smooth surface for the liner. On two occasions, the clay lining was washed away and needed to be replaced. The wet weather caused delays and additional cost through re-working the clay liner (refer to Figure 17).

Ideally construction would be scheduled to be outside of known rainy seasons. However project delivery dates dictated construction through this period.

It was found that the leak detection system in the floor of the pond became useful for removing collected rainfall. However the gravel lined trench did get impacted by sediment which needed to be removed. The leak detection system is shown in Figure 18.

Figure 17: Re-working earthworks following rainfall

Figure 18: Leak detection system and commencement of lining (eastern pond)

5.4 The Lagoon Liner

5.4.1 Design Issues and Changes

The lagoon liner was installed on internal batter slopes of 2.5:1 (horizontal to vertical). This change was required to achieve the design CAL volume. Internal batter slopes of 2:1 would have been technically feasible, however due to safety and constructability concerns by the liner installation contractor, 2:1 internal batter slopes were deemed to be too steep. Subsequently the internal batters were changed to be 2.5:1 which achieved a compromise between lagoon volume optimisation and ease of construction.

The internal batter slopes were mostly free of rock and in some locations where there was some rock a clay material was imported, placed and compacted so as to provide a protective layer to the 1.5mm HDPE liner.

5.4.2 Construction Issues

The construction of the lagoon liner was delayed by some unpredicted events. The main causes of construction delays were:

- Upon arrival to Australia the shipping container carrying the liner and cover material was randomly selected by the Australian federal government for security x-rays;
- Rainfall during construction was much higher than anticipated. The lagoons would capture water during a rainfall event and hold the water. The water would then be pumped out of the lagoons and left for a minimum for 3 to 4 days until the lagoon surface was suitable to be traversed and lined; and
- Excavation of the liner anchor trench was made difficult due to large rock being found during excavation of the trench. This required over excavation of the liner trench and the importing and compaction of suitable clay material on the inside top corner of the anchor trench. This was required to provide a smooth and sound foundation for the liner and cover.

5.5 The Lagoon Cover

5.5.1 Design Issues and Changes

The lagoon cover was constructed from 2.0 mm HDPE geomembrane.

The lagoon cover includes rainwater removal system. As described in Section 4.7.3 this was originally intended to be a passive gravity flow system. The passive rainwater removal system makes use of the fact that the discharge point is lower than the CAL cover rainwater sump which means water should flow by gravity. However it was found following construction that the 50 mm HDPE pipe used for the drain floated under the cover. A syphon action was required to get water to move over this high point to the outside of the CAL. The syphon action was reluctant to start passively.

The system was revised during construction to include:

- two 50 mm HDPE pipes per lagoon which ran from the rainwater sump over the CAL cover and anchor trench and then sub surface to the outside of the CAL embankment; and
- a high pressure water supply delivered through a 25 mm HDPE pipe to the rainwater sumps.

The high pressure water is used to start a syphon. Probes on the cover detect water and activates the relevant high pressure water solenoid valve for 30 seconds. This water is injected into the 50 mm HDPE drainage pipe starting a syphon action. The control probe is 24 V (low voltage) which makes the system intrinsically safe and keeps electrical power supply away from the cover. The system is shown in Figure 19.

Figure 19: Rainwater removal system

The cover weigh down system is important for wind control, gas control and rainwater removal (see Figure 20). The polyethylene pipes used are filled with water and are provided with a top up sources supplied from a make-up tank which keeps the pipes topped up due to losses from contraction and expansion. The pipes are held to the cover using saddles that allow movement (see Figure 20).

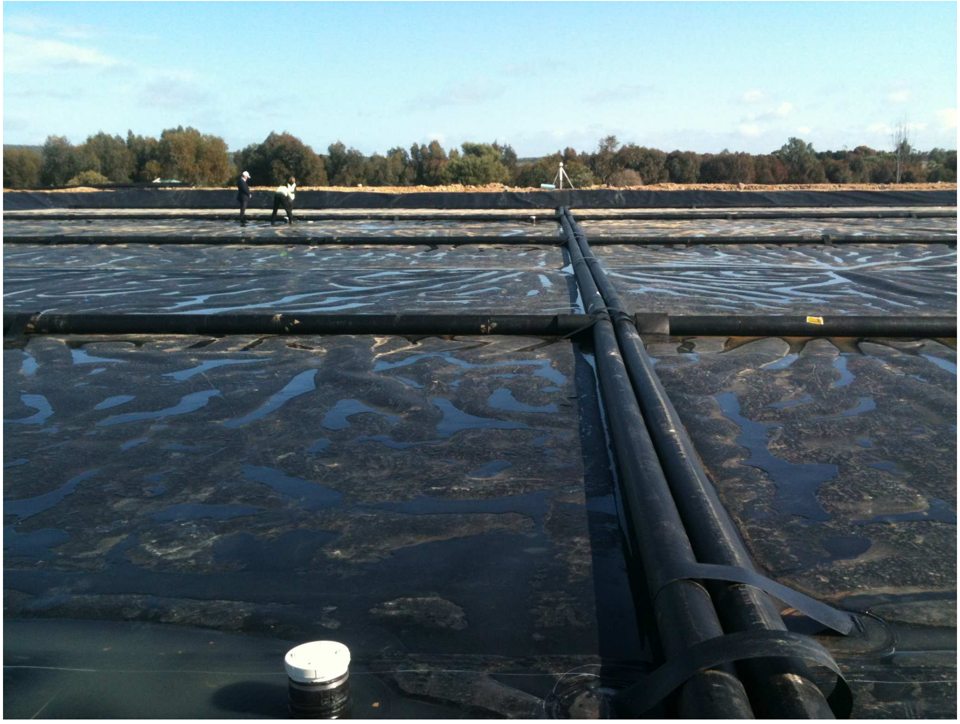


Figure 20: Cover weigh down system during construction

5.5.2 Construction Methodology

The lagoon covers were winched and floated from one side to the other, across the lagoons, under the support of floating pontoons. For cover installation it was therefore necessary to fill the lagoons and have a water source available. The preference of the cover installation contractor was to use a clean water source or to use river water to fill the lagoons. Neither of these water sources were available at the Murray Bridge site and it was agreed to use post DAF effluent to fill the lagoons. The post DAF effluent was heavily dosed with chemicals to ensure effluent in the lagoon was as clean as possible. There was potential for the effluent to self-initiate anaerobic digestion, become ‘active’ and produce methane. It was identified that ‘active’ effluent would create potentially significant safety issues for cover installation staff. Dosing the effluent with high levels of chemical helped ensure the effluent remained inactive.

The methodology for winching and floating of the covers is shown in Figure 21. Installation of the cover on the western CAL is shown in Figure 22.

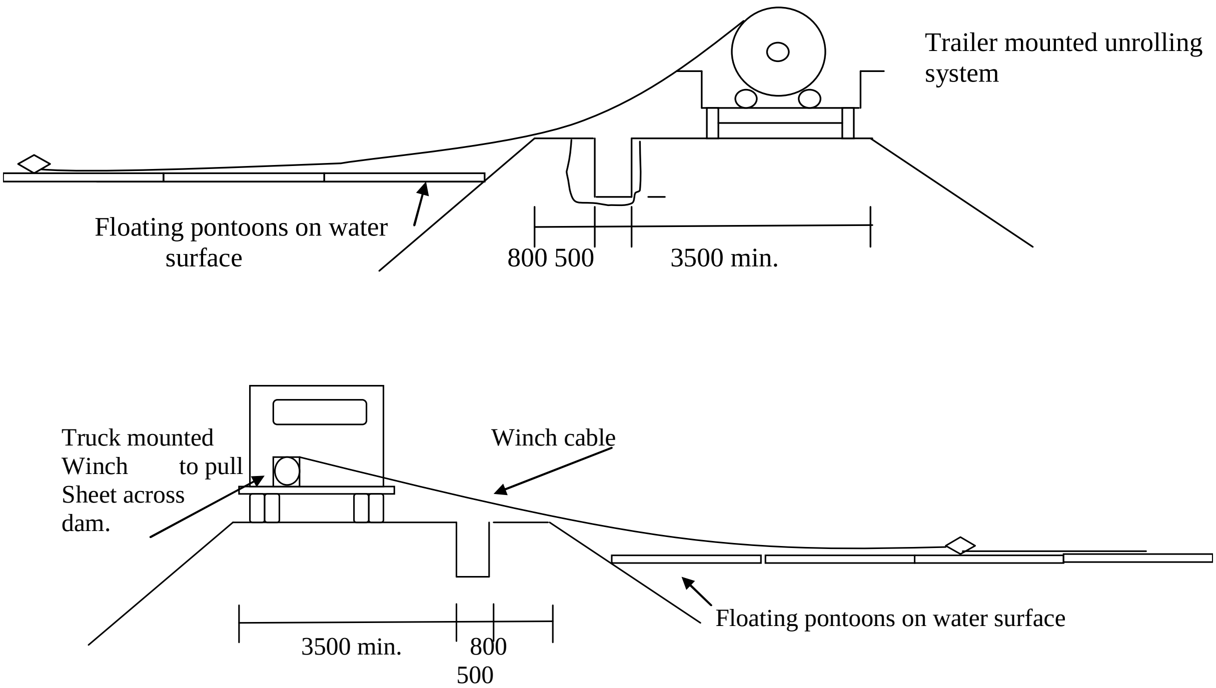


Figure 21: Lagoon cover installation methodology

Figure 22: Installation of cover on western CAL using floating pontoon

The general lagoon cover construction methodology was:

1. Install the liner on the western lagoon;
2. Start filling the western lagoon with inactive effluent;
3. Install the liner on the eastern lagoon while the western lagoon was filling with inactive effluent;
4. Start filling the eastern lagoon with inactive effluent;
5. Install the cover on the western lagoon while the eastern lagoon was filling with inactive effluent; and
6. Install the cover on the eastern lagoon.

Following the winching and floating of the cover the cover was then secured into the anchor trench using compacted earth. After the cover was successfully secured in the anchor trench it was then possible to install the rainwater collection system.

Figure 23: Anchor trench with cover installed in western CAL

The construction methodology utilising in situ welding of each strip resulted in a better cover system compared to pulling a fully constructed cover across the pond. A better shape was achieved and when under slight pressure form the biogas should mirror the internal batters of the lagoon. The installed cover on the eastern CAL prior to any biogas generation is shown in Figure 24.

Figure 24: CAL cover (eastern CAL) prior to biogas generation

5.5.3 Post Commissioning Issue

Each CAL includes a pressure sensor which is continuously logged to monitor the pressure under each cover. It was noted that the eastern CAL did not generate as much pressure as the western CAL. It could not be determined from operational data if this was due to less gas generation (as the combined biogas is delivered and metered as one stream) or a leak.

It was also noted that the biogas production was falling despite continued COD reduction in the CALs (refer to Figure 25) which indicated a potential leak.

A methane meter was used to check the integrity of the CAL cover system and a leak was identified along the southern and eastern sections of the anchor trench of the Eastern CAL. The anchor trench was excavated in 5 m sections with the backfill material removed to a depth of 300 mm and width of 500 mmm. The anchor trench was then backfilled with imported compacted clay material.

Monitoring has shown this remedial work to be effective.

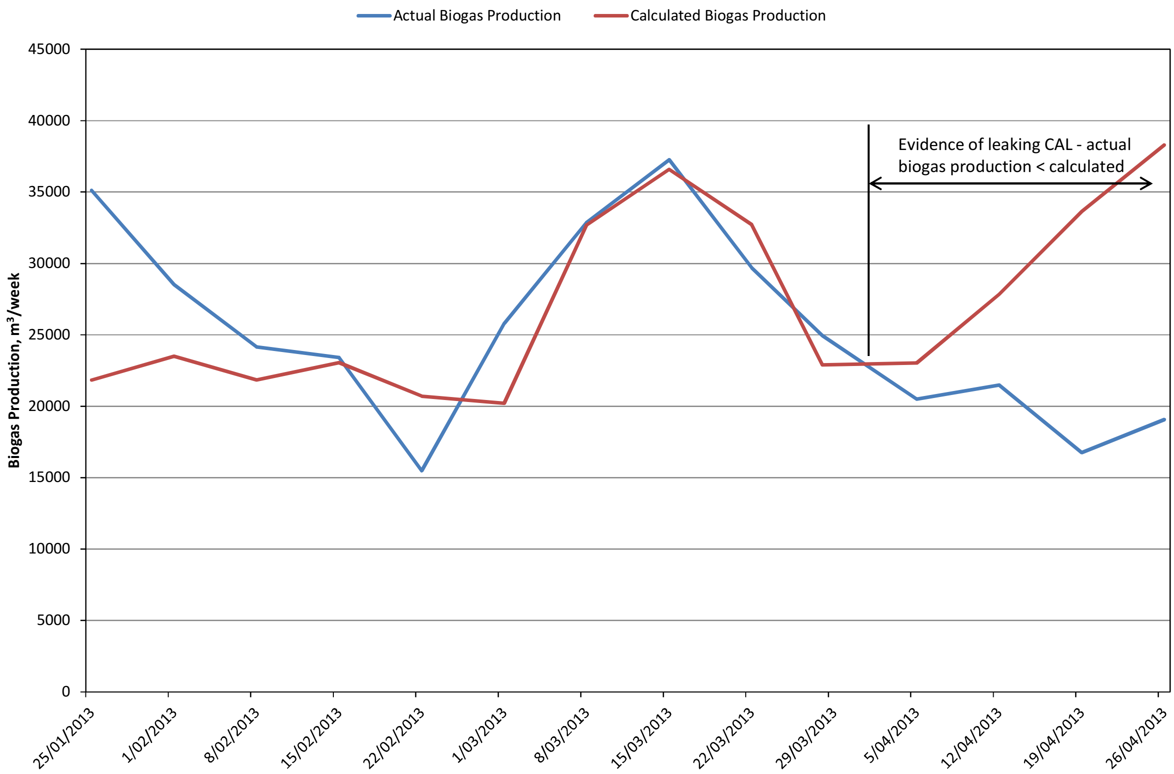


Figure 25: Actual vs calculated biogas production

5.6 Effluent Distribution System

5.6.1 Design Issues and Changes

The effluent distribution system is detailed in Appendix 1.

Construction of the effluent distribution system involved the installation of sludge removal pipes, leak detection pipe work and the installation of PVC pipe and electrical conduits in a common trench. A coordinated approach between all parties was required to ensure all major services did not impact adversely impact each other or other components of the CAL.

The areas where the effluent distribution system required design changes were:

- Installation of the effluent outflow pipe from the eastern CAL along the entire length of both CALs to the pump sump. This pipe is a gravity main and as such it required a constant grade at a minimum of 1%. This effluent outflow pipe also crossed the main sludge pump to DAF services trench;
- Installation and design of the leak detection pipes to ensure the pipe would be an adequate distance from the bottom of the anchor trench;
- Installation and design of the sludge removal pipes to ensure they would be an adequate distance from the bottom of the anchor trench and that they would not impact on the main DAF to sludge pump services trench; and
- Ensuring pipe and services trenches would be clear of the access road along the top embankment.

Comes components of the effluent distribution system are shown in the following figures.

Figure 26: Eastern CAL outflow weir

Figure 27: Sludge removal pipe penetrations on the western lagoon

Figure 28: Lined eastern CAL showing sludge removal pipes and MegaFlo gas collection

Figure 29: Inlet to eastern CAL during initial filling

5.6.2 Construction Issues

Construction issues identified included:

- Avoiding service interference was the greatest challenge requiring changes during the construction process;
- Identifying the need for a control valve on the pipes that went from the end of each CAL to the effluent sump. Without these, flow to the sump could not be stopped in the event that maintenance was required; and
- Dealing with the wrong pipe material. The effluent distribution pipe was ordered as rubber ring jointed PVC. As this pipe at times would need to act as a suction line, it was necessary to encase each joint with concrete.

Original the pipe bridge supporting sludge, gas pipes and controls was to be located adjacent to the anchor trench on the inside of the embankment crest. This would have made access to the ponds difficult. This arrangement was changed during construction so that it was located on the outside of the embankment crest which allowed easier and safer access. The pipe bridge is shown in Figure 30.

Figure 30: Pipe bridge located on outside of embankment

5.7 Completed CALs

Views of the completed CALs are shown in the following figures.

Figure 31: Western CAL showing some biogas generation

Figure 32: Central distribution weir and cover weight top-up water tank

Figure 33: Eastern CAL with flare in background

Figure 34: Flare and security fence

6 Commissioning

Commissioning of the CAL system was undertaken for various elements as follows:

- Mechanical commissioning;
- Biogas train commissioning; and
- Biological commissioning.

The practical completion of the D&C contract was achieved on 4 October 2012 following the mechanical commissioning and commencement of the biological commissioning. This was slightly delayed due to rain and a hold up with supplies for the final transfer pump station which meant that the effluent stream could not be commissioned. Practical completion is the point where all elements have been constructed and the system commissioned to run effluent from the DAF, through the CALs, and out to the ponds on the Pahl farm.

Commissioning of the gas stream is a one to two month process following this as it takes this time period for the four different microbiological populations to establish during the biological commissioning stage.

6.1 Mechanical Commissioning

This stage included commissioning of all pumps, pipes and controls to transfer effluent from the DAF through to the Pahl farm.

Mechanical commissioning could not commence until completion of the final transfer pump station so that the effluent moving through the CAL system could be transferred off-site.

Operation of the mechanical system was systematically checked and most system performed as expected.

Mechanical commissioning included the sludge removal system. Although the pumps used are self-priming to 10 m, it was difficult to retain the prime in the system as sludge drains back to the ponds and gases enter the lines. Air release valves and water injection points were installed to in the suction lines. Once the gases are vented and the system primed the sludge removal system performs as expected.

It has not been necessary to operate the sludge removal/return system since its initial commissioning. However, the process of releasing accumulated gases and priming will need to occur manually each time the system is used. Actuated valves and automated water injection would be required to allow automation of the sludge removal system.

Flow balancing between the two CALs was found to be more difficult than expected. The level in each CAL is controlled by the outflow weir and adjusting these weirs to achieve equal flow proved to be difficult. Once a balance was achieved however, the gravity system adequately balances flow between the two CALs and does not require intervention.

No other major issues were identified in the mechanical commissioning process.

6.2 Biogas Train Commissioning

Commissioning of the biogas delivery system and flare is an important part of CAL start-up. The biogas train could not be commissioned until sufficient biogas was being generated. For construction purposes, the CALs were filled with relatively low strength effluent which meant there was some, but not substantial biological activity once the ponds were covered.

Increased feed to the CALs commenced in late September and cover inflation and pressure were closely monitored in the first four weeks of commissioning. Once there were visible signs of biogas production (bludging covers) and the pressure consistently exceeded 10 to 15 Pa, it was deemed that there was sufficient biogas to commission the flare.

The biogas delivery system and flare were commissioned on 26 November 2012; approximately two months after the feed to the CALs was increased. The flare itself went through a two stage commissioning process:

- Initial commissioning 26 November 2012
- Final commissioning 19 March 2013

Biogas readings are recorded daily (totalled over weekends). Details of biogas production since commissioning are presented in the Section 6.3.4.

The size of the biogas collection lines presented a minor commissioning issue. The biogas from the western CAL is collected in a 100 mm diameter main and travels about 110 m to the point where it is joined with the 100 mm diameter biogas line from the eastern CAL. After this junction, the biogas line increases to 150 mm diameter. Due to the shorter distance to the eastern CAL, it was found that biogas was being preferentially drawn from the eastern CAL causing negative pressures. A larger biogas line to the western CAL would reduce this effect.

A valve in the biogas line from the eastern CAL was partially shut down which now balances the gas flow.

6.3 Biological Commissioning

Commissioning an anaerobic pond with meat processing water is usually a relatively straight forward process as the incoming raw effluent contains high levels of suitable bacteria and the effluent temperature is conducive to a reasonably rapid start up. However there are risks in the process that need to be carefully managed. A commissioning plan was developed to guide the process (Johns Environmental, 2012).

It was noted that the main challenge for this site was that is not possible to inoculate the CALs with sludge containing methanogenic bacteria (Johns Environmental, 2012). Therefore the system would need to establish the required biological activity.

6.3.1 Commissioning Plan

A commissioning plan was prepared by the D&C contractor. The objectives of this plan were to:

1. Ensure the start-up of the CALs is smooth and as fast as possible;
2. Provides guidance points to identify possible departures from Objective 1 and permit remedial action; and
3. Provide a monitoring program for commissioning and for regular operation.

As mentioned previously, heavy chemical dosing in the DAF was used to fill the CALs with relatively low strength effluent during construction. The commissioning plan was therefore based around increasing the feed to the CALs to establish microbial action. A summary of the plan is provided in Table 6.1.

Table 6.1 – CAL commissioning plan

Timing	Actions	Monitoring
Day 1	• Commence effluent flow into CALs at full rate, split evenly between the two CALs • Operate the DAF with no chemical dosing • Check operation of CAL inflow and outflow system to ensure functioning correctly	• System flow
Weeks 1 to 4	• Continue feeding primary treated effluent to CALs at full rate, split evenly between the two CALs • Operate the DAF with no chemical dosing • Observe discharge flow • Look for cover inflation as biogas production begins (slowly – expect 2 to 4 weeks before significant biogas production occurs) • Discontinue feed if there is any trouble in the facility that causes abnormally strong, hot or fatty feed	• System flow • Temperature (daily) • pH (daily) • COD weekly • Biogas production (daily) • Methane content of biogas (daily) • Volatile Fatty Acids (twice weekly) • Total alkalinity (twice weekly) • Ammonia (weekly) • Total suspended solids (weekly) • Oil and grease (weekly)
Subsequent weeks	• Continue feeding primary treated effluent to CALs at full rate, split evenly between the two CALs • Continue operating the DAF with no chemical dosing • Observe discharge flow • Observe biogas and cover inflation – biogas production should be significant after 4 weeks of operation • Discontinue feed if there is any trouble in the facility that causes abnormally strong, hot or fatty feed • Discontinue feed for 24 hours if CAL discharge COD goes above 5,000 mg/L	• System flow • Temperature (daily) • pH (daily) • COD weekly • Biogas production (daily) • Methane content of biogas (daily) • Volatile Fatty Acids (weekly) • Total alkalinity (weekly) • Ammonia (weekly) • Total suspended solids (weekly) • Oil and grease (weekly)

Source: Johns Environmental, 2012

The commissioning plan identified key risks in starting up CALs and defined the cause and trigger points which are summarised in Table 6.2. A monitoring plan was established to monitor these trigger values (refer to Table 6.1).

Table 6.2 – Risks in starting up CALs

Effect	Cause	Trigger Value
High water temperature	Hot feed streams	CAL effluent > 38^{o}C
Excess COD load	High & variable COD levels in feed to CAL	COD effluent > 5,000 mg/L; foaming discharge
Low pH	Biological imbalance	pH < 6.6
No or little biogas production	Poisoning	Biogas production falls
High VFA levels	Poisoning	VFA/TA > 0.5

Source: Johns Environmental, 2012

6.3.2 The Commissioning Experience

Biological commissioning of the CALs commenced on 24 September 2012.

In early November, monitoring showed that the CAL pH was falling and a soda ash dosing program commenced to raise the CAL pH and dosing at the DAF was used to lower the inflow COD. The soda ash was added directly into each CAL through the inspection ports.

During December, aided by the two week facility shutdown and dosing, the CAL discharge pH improved and the discharge COD fell to approximately 4,000 mg/L. From the middle of January 2013, both CALs have consistently improved in performance with the discharge COD falling to between 2,000 to 3,000 mg/L and going below 2,000 mg/L by the end of April 2013. At the same time the pH improved and there was excellent biogas production with high methane content. This indicated that the sensitive and slow growing methanogenic bacteria population was well established and active.

6.3.3 Organic Loading and Removal

The design organic loading rate for the CALs was:

- 0.54 kgCOD/m^3/day
- 0.40 kgBOD/m^3/day

The average organic loading rate on the CALs since the start of 2013 has been:

- 0.34 kgCOD/m^3/day
- 0.17 kgBOD/m^3/day

Therefore the organic loading rate has been within the design values since the start of 2013.

Organic removal rates through the CALs since the start of 2013 are shown on Figure 35. Both are showing increasing trends with the BOD removal approaching the design target of 80%.

Excluding the Christmas shut-down period, the average hydraulic residence time in the CALs has been 16.8 days.

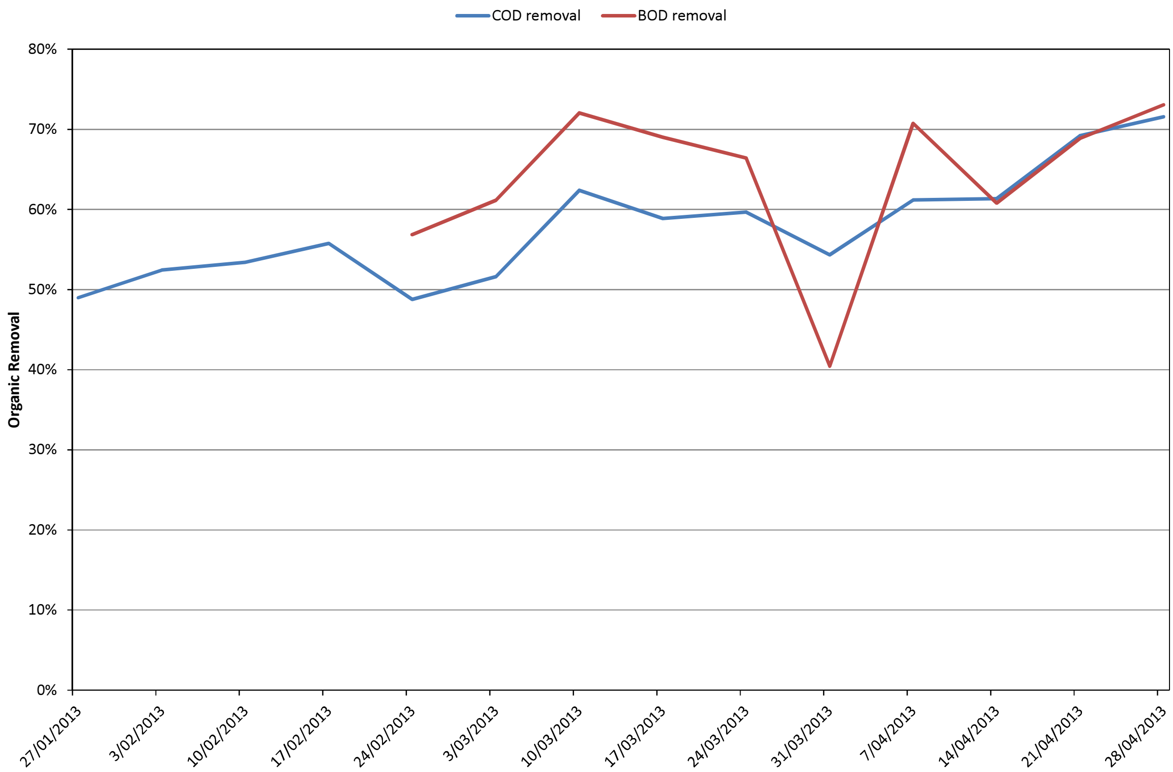


Figure 35: Organic removal rates

6.3.4 Biogas Production

Daily biogas production from the CALs is shown in Figure 36.

The start-up period is evident at the start of the graph with the biogas production gradually increasing to approximately 6,000 to 7,000 m^3/day in the middle of January 2013. Biogas production then fell to between 3,000 and 4,000 m^3/day as the inflow reduced by 1 to 2 ML/week and the COD remained low due to DAF dosing.

The DAF dosing was reduced in early March with the aim of increasing the COD feed to the CAL to around 7,000 to 8,000 mg/L. This increased biogas production through March.

The average biogas production through March 2013 was 0.52 m^3 per kg of COD removed which is consistent with the desk top review data.

The average methane content of the biogas is 55%.

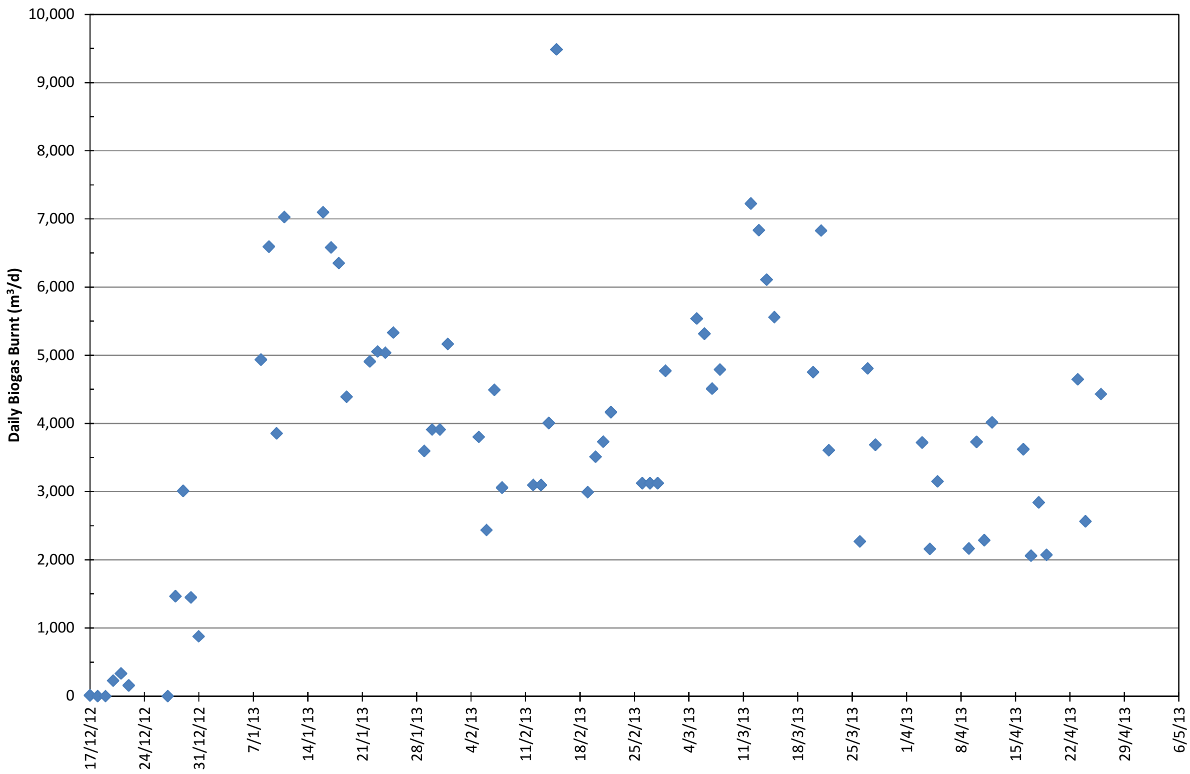


Figure 36: **Daily biogas production**

6.4 Further Research on Biogas Production

The Stage 2 MLA project commenced with the commissioning of the CALs. This project, P.PIP.0340 “Manipulation of the newly constructed wastewater treatment system at Murray Bridge to maximise biogas production” has the following four objectives:

1. Determine waste water load composition and characteristics that generate the maximum amount of biogas;
2. Determine how best to minimise chemical requirements for the DAF;
3. Identify impact of sludge recirculation on biogas production; and
4. Cost benefit analysis of construction of biogas capture and reuse.

This project will provide further operational details and report fully on the commissioning process.

7 Project Findings

7.1 Overview

The key findings from this project relate to:

- Design approach;
- The CAL size and configuration;
- Internal pond batters;
- Anchor trench;
- Surface water removal system;
- Minor mechanical design modifications;
- Services;
- Construction timing; and
- Commissioning.

7.2 CAL Sizing and Configuration

The final twin 20 ML CAL design results in a design organic loading rate of 0.54 kgCOD/m^3/day which is at the lower end of the range of published data.

To the end of April 2013, the loading rate has averaged 0.34 kgCOD/m^3/day with an average hydraulic residence time of 16.8 days. This loading rate is lower than the range of published data (refer to Table 3.5).

Data to the end of April 2013 shows that the CALs are gradually moving towards the design organic removal rate of 80%. Designers are confident that stable CAL operation with 80% COD/BOD removal will be achieved.

The twin CAL configuration is preferred to provide operational flexibility and redundancy. If one CAL is used, the upstream DAF system could be used to lower the strength of the inflow so that the loading remained within the design range.

7.3 Pond Batters

Initial design parameters included internal batters of 3:1 (H:V). Internal batter slopes of 2:1 would have been technically feasible, however due to safety and constructability concerns raised by the liner installation contractor, 2:1 internal batter slopes were deemed to be too steep. Subsequently the internal batters were changed to be 2.5:1. The CAL liner was successfully installed on these batters.

Therefore maximum internal batters of 2.5:1 are recommended for lined lagoons.

7.4 Anchor Trench

Excavation of the liner anchor trench was made difficult due to large rock being found during excavation of the trench. This required over excavation of the liner trench and the importing and compaction of suitable clay material on the inside top corner of the anchor trench. This was required to provide a smooth and sound foundation for the liner and cover.

To avoid this situation, it is recommended that the top 1 m of pond embankments be constructed using select fill material if the pond is being constructed in areas that contain rock.

Select clay material also needs to be used for backfilling the anchor trench to ensure a good seal is achieved for the CAL cover.

7.5 Surface Water Removal System

A passive surface water removal system is technically possible. This avoids the need to have a pump on the cover which improves safety and wear. It does however require that the discharge pipe pass through the pond and liner. As experienced at this site, this pipe is prone to floating which may inhibit drainage by gravity, or prevent a syphon action.

The solution adopted using a high pressure water feed to start a syphon is working well. Probes on the cover detect water and activate a high pressure water solenoid valve for 30 seconds. This water is injected into the 50 mm HDPE drainage pipe starting a syphon action. The control probe is 24 V (low voltage) which makes the system intrinsically safe and keeps electrical power supply away from the cover.

7.6 Mechanical Design

7.6.1 Operational Flexibility

It is prudent to have operational flexibility of the influent, effluent and sludge removal/distribution system. In the case of the TFI CAL it has been a simple design task with minimal extra cost to build operational flexibility into the effluent distribution system. CALs are a relatively new technology so the design philosophy has been to incorporate operational flexibility. The additional infrastructure required to increase the operational flexibility was minimal.

7.6.2 Flow Balancing

Flow balancing between the two CALs was found to be more difficult than expected. The level in each CAL is controlled by the outflow weir and adjusting these weirs to achieve equal flow proved to be difficult. Once a balance was achieved however, the gravity system adequately balances flow between the two CALs and does not require intervention.

As discussed in Section 4.7.4, the inflow weir box has other roles including a mixing point for possible sludge injection and a point for drawing effluent to pump through the sludge removal lines. Therefore maintaining the gravity flow system maintains these functions.

7.6.3 Sludge Removal System

During commissioning of the sludge removal system, it proved difficult to retain the prime in the system. The sludge pumps are located on the pond embankment and suction lines are therefore drawing from a depth of about 7.5 m. Sludge drains from the lines and gas generated in the CAL collects in the sludge removal line causing the system to lose prime. Air release valves were installed to release gases that accumulated in the suction lines. Once the gases were vented and the system is primed the sludge removal system performs as expected.

The process of releasing accumulated gases and priming will need to occur manually each time the system is used. If automated sludge removal is required in the future an automated priming system will need to be installed.

This could be avoided is the sludge pumps were located lower than the suction lines, however the ability to achieve this would depend on site conditions as it is most likely effluent ponds would be constructed with floor levels lower than surrounding ground levels.

7.6.4 Biogas Collection

Movement of biogas from the western CAL is restricted by the size of the biogas collection line. The result is that biogas is preferentially drawn from the closer (eastern) CAL. A larger biogas line to the western CAL would reduce this effect.

7.7 Services

There are many services in and around the CALs. Avoiding service interference was a challenge requiring changes during the construction process. A coordinated approach between all parties was required to ensure all major services did not impact adversely impact each other or other components of the CAL.

Locating above ground services away from the edge of the CAL was an advantage, allowing easier and safer access.

7.8 Construction Timing

The bulk earthworks, particularly the finishing of the internal surface for liner placement was significantly impacted by rainfall. The area received more than double the annual average rainfall during the construction period.

The internal pond walls were lined with clay to provide a smooth surface for the liner. On two occasions, the clay lining was washed away and needed to be replaced. The wet weather caused delays and additional cost through re-working the clay liner.

Ideally construction would be scheduled to be outside of known rainy seasons. However project delivery dates may not allow this to occur.

7.9 Biological Commissioning

CALs are considered to be fairly robust systems. However the experience gained during the commissioning of the CALs demonstrates that biological commissioning is a critical process that needs to be closely monitored and controlled.

The use of seeding with methanogenic bacteria may quicken that start-up process, although it is not essential. Without seeding, it took approximately 8 weeks to generate sufficient biogas to commission the flare.

It is prudent to include discussion of the likely commissioning timeframes and potential issues in the planning approval applications so that approval authorities and the community are aware of the process.

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9 Appendices

9.1 Appendix 1 – CAL Trenching and Services Layout