GHD

Dairy Australia

Anaerobic Digestion as a Treatment and Energy Recovery Technology for Dairy Processing Waste Streams

Report

June 2017

Executive Summary

Anaerobic digestion is a key treatment method for high strength wastes and presents an opportunity to generate a useful by-product (biogas), providing the potential for waste to energy.

This report provides information on anaerobic digestion technologies for engineering and technical staff at dairy processing plants who wish to conduct an initial feasibility of anaerobic treatment technologies for their plant. The topics covered in this report are:

Wastewater Characteristics and Disposal Routes

An overview of the dairy processing wastewater characteristics in Australia is provided together with a discussion of key wastewater characteristics that are important for successful operation of anaerobic treatment. Disposal routes (sewer, surface water, agricultural land and on-site reuse) guidelines governing the discharge, and examples of trade waste charges at different sites are explored.

Anaerobic Digestion Technology Review

A brief description of various anaerobic digestion technologies is presented and the advantages and disadvantages of each system are summarised. Comparison of anaerobic digestion technologies are captured in Section 0. The technologies reviewed are;

- Uncovered anaerobic lagoons
- Covered anaerobic lagoons (CAL)
- Constructed digestion tank reactors
- Proprietary high rate anaerobic digestion systems [Anaerobic flotation reactor (AFR), Upflow Anaerobic Sludge Blanket (UASB) and Anaerobic Membrane Bioreactor (AnMBR)

Covered Anaerobic Lagoon Design Criteria

The design of CAL systems is discussed in detail in Section 5, covering design criteria and typical design values, considerations that should be incorporated and common pitfalls. This provides guidance on the basic design of CAL and associated ancillary equipment including biogas capture, commissioning, monitoring and operation and maintenance. CAL capital cost estimates were developed (for small, low-medium, high-medium and large plants) and provided in Section 5.4.

CAL Design Criteria	Unit	Typical Range
Influent characteristics		Temperature: 30- 35°C BOD 2,500 – 25,000 mg/L Alkalinity > 1,500 mg/L as $CaCO_3$
Loading rates	kg.COD/m^3.day	0.03 – 0.4
Pond HRT	days	10 – 40
Pond depth	m	5 – 7
Pond freeboard	m	0.5
Pond geometry	Length to width ratio	2-3 : 1
Pond slope	-	3:1 (sandy soils) 2:1 (clay soils)
Effluent characteristics		pH: 7.0 -7.6 VFA: 50 – 500 ppm as acetic acid

CAL Design Criteria	Unit	Typical Range
		Alkalinity: 2,000 – 3,000 ppm as $CaCO_3$ Ratio of VFA / Alk: 0.1 – 0.5 Ratio of VFA / Alkalinity is an important factor.
Biogas generation	m^3 biogas produced per kg COD removed	0.5
	m^3 CH_4 produced per kg COD removed	0.25 - 0.35

Biogas Conditioning and Conversion

Biogas conditioning requirements and conversion technologies are discussed in Sections 6 and 7 and associated capital and operating costs (small, low-medium, high-medium and large plants) are summarised. Biogas conditioning and conversion technologies considered are:

Biogas conditioning

- H_2S removal (Dry, wet scrubbing, biological tricking filter, adsoprtion)
- Moisture removal (Condensate and sediment trap, U-trap and refrigeration)

Biogas conversion

- Gas flaring
- Boiler
- Internal combustion engines
- Cogeneration
- Microturbines

Case Study

A case study is presented for Goulburn Valley Water's Tatura wastewater treatment plant. The design aspects and biogas generation are outlined to provide an understanding of the success factors and lessons learnt for the wider audience, but especially those considering installation of a CAL.

Business Case Evaluation

Lastly, the application and feasibility of covered anaerobic lagoons were considered from the points of view of:

- The water authority
- The dairy company
- The electricity generator / provider.

Risks and opportunities for treatment scenarios are also discussed.

Abbreviations

AD	Anaerobic Digestion
AFR	Anaerobic Flotation Reactor
AL	Anaerobic Lagoon
AnMBR	Anaerobic Membrane Bioreactor
BOD	Biochemical Oxygen Demand
ASP	Activated Sludge Process
CAL	Covered Anaerobic Lagoon
CH_4	Methane
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CSTR	Continuous Stirred-Tank Reactor
FOG	Fats, Oils and Grease
GVW	Goulburn Valley Water
HDPE	High Density Polyethylene
HRAL	High Rate Anaerobic Lagoon
HRT	Hydraulic Retention Time
H_2S	Hydrogen Sulphide
IC	Internal Combustion
LDPE	Low Density Polyethylene
LLDPE	Low Linear Density Polyethylene
PE	Polyethylene
RO	Reverse Osmosis
SAR	Sodium Absorption Ratio
SBR	Sequencing Batch Reactor
SRT	Solids Retention Time
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
UASB	Upflow Anaerobic Sludge Blanket
VFA	Volatile Fatty Acids
WWTP	Wastewater Treatment Plant

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1. Introduction

1.1 General

The dairy processing industry generates a wastewater which contains high concentrations of organic matter (expressed as biochemical or chemical oxygen demand, BOD or COD respectively), nutrients (nitrogen and phosphorous), fats, oils and grease (FOG) and total dissolved solids (TDS) or salinity. Treatment and disposal of this wastewater in a cost effective and environmentally sustainable manner is a significant challenge for the dairy industry.

Depending upon site location and available wastewater disposal routes, trade waste charges for sewer disposal can vary considerably. As most sewer charges are load based, high organic loads if untreated or inadequately treated will incur a substantial fee to the overall plant operation. Reduction of trade waste charge is only possible by implementing an effective pre-treatment, which would remove contaminants ideally to a level low enough to avoid significant charges.

A selection of current trade waste charges from around Australia is provided for reference in Section 2. A comparison is also provided of annual trade waste charges which would be incurred for a fictitious plant located if it was located in different regions. The results, show that the majority of the charges are related to wastewater flowrate and BOD. The analyse also highlights potential savings to the business that could be realised by employing an effective organic removal process, such as anaerobic digestion. While there are numerous treatment technologies, anaerobic digestion is a key treatment method for high strength wastes and presents an opportunity to generate a useful by-product – biogas, providing the potential for waste to energy.

This report provides information and focusses on anaerobic digestion technologies, and aims to assist engineering and technical staff at dairy processing plants when conducting an initial feasibility of anaerobic treatment technologies for their plant, as well as providing key insights for plant engineers operating existing anaerobic digestion facilities.

1.2 Purpose of this report

This report presents a review of anaerobic digestion technologies for wastewater streams produced by the Australian dairy processing industry together with a case study involving a dairy processor, water corporation and power generator.

The purpose of the report is to provide a reference document for the Australian dairy processing industry that provides engineering and technical staff with credible information to assist with decision making when considering an anaerobic digestion project and key insights into understanding an operational system. The intent is to encourage implementation of successful anaerobic digestion projects within the Australian dairy industry where it makes sense and to discourage projects where it does not. The report therefore also outlines conditions where local factory, wastewater and environmental conditions are poorly suited to the technology.

1.3 Scope and limitations

1.3.1 Work scope

The scope of work involved in developing this manual included:

- A review of typical wastewater characteristics of dairy processing industry
- A review of Australian dairy wastewater treatment requirements

- A review of available anaerobic digestion technology
- A review of biogas utilisation technologies
- A review of biogas conditioning technologies
- Presentation of a dairy digestion case study

1.4 This report

Section 2 outlines the characteristics of dairy wastewater.

Section 3 discusses the disposal routes available to the dairy wastewater, discharge requirements and comparison of trade waste charges with and without the AD process.

Section 4 discusses anaerobic digestion technologies to treat dairy processing wastewater.

Section 5 discusses design criteria for covered anaerobic lagoon systems, ancillary equipment and associated capital and operating cost.

Section 6 discusses biogas conditioning technologies to remove pollutants and identifies associated capital and operating costs.

Section 7 discusses biogas conversion technologies and associated capital and operating cost.

Section 8 presents a case study of anaerobic digestion in the dairy industry.

Section 9 presents key risk and opportunities when considering anaerobic digestion in the dairy processing industry.

2. Characteristics of Dairy Processing Effluents

2.1 Overview

This section gives an overview of the dairy processing wastewater characteristics in Australia. The typical ranges of wastewater pollutants generated by the dairy processing industry are presented and the wastewater characteristics that are important for successful operation of anaerobic treatment systems are explained.

2.2 Dairy Processing Wastewater Characteristics

Dairy processing wastewater characteristics are highly variable based on the products produced at the site. Such products could include:

- Milk
- Colostrum
- Liquid milk products
- Cream and thickened cream
- Butter, butter concentrate, buttermilk, concentrated buttermilk, dairy blend, ghee, and anhydrous milk fat (butter oil)
- Casein, caseinate, and cheese
- Whey, whey cream and concentrated whey cream
- Cultured milk and yoghurt
- Ice-cream and ice-cream mix
- Buttermilk powder, lactose powder, milk sugar, powdered milk, skim milk powder, whey powder, milk protein
- Powder and other milk concentrates

Typical characteristics of wastewaters from various types of dairy facilities (product based) adapted from Watkins & Nash (2010) [1] is shown in Appendix A.

It is quite common for dairy processing facilities to produce a combination of dairy products resulting in a combined waste stream with unique characteristics. Despite this inherent variability in wastewater characteristics, dairy wastewater streams typically comprise high concentrations of organic matter (expressed as biochemical or chemical oxygen demand, BOD or COD respectively), nutrients (nitrogen and phosphorous), fats, oils and grease (FOG) and total dissolved solids (TDS) or salinity.

Acknowledging that there will be significant variability, typical waste values derived from data from a range of Australian dairy processing plants are presented in Table 1.

The waste characteristics presented were compiled from survey results provided by Dairy Australia. A total of 10 dairy manufacturer sites participated in the survey. The complete data set and further information are included in Appendix A.

Table 1 Dairy Processing Wastewater Quality

Parameter	Typical Value	Range
pH	-	4 – 12
FOG, mg/L	500	100 – 1,200
TSS, mg/L	1,500	250 – 12,000
TDS, mg/L	3,000	700 – 7,000
BOD_5, mg/L	2,500	700 – 15,000
COD, mg/L	4,500	500 – 80,000
TN, mg/L	100	30 – 300
TP, mg/L	50	10 – 150

As noted above, in general terms, the wastewater varies dependent on type of dairy products:

- Milk processing plants produce low strength organic waste with a COD concentration between 70 – 1,400 mg/L. Total solids is also present in the lower range at approximately 1,500 mg/L [2]
- Manufacturers of butter and milk powder products typically produce medium to high strength organic waste streams with COD concentrations, between 1, 900 to 2,500 mg/L. Total solids is higher for this waste compared to milk processing plants [2]
- Waste from cheese production is high in COD concentration at approximately 2,000 to 5,000 mg/L and often has high levels of salinity. Where milk whey is present (by-product of cheese processing), an even higher concentration of organic loads is usually expected. Concentrated whey streams have a BOD of approximately 30,000 to 50,000 mg/L [3]
- In terms of total phosphorous (TP) the largest contributor is cheese manufacturing, followed by butter and milk powder facilities, then milk processing

Finally, manufacturing practices significantly influence waste characteristics. Milk and any milk product wastage (e.g. due to minor spillages or major dumps due to contamination or spoilage) increases the total organic load of the effluent as does frequent product changeovers resulting in more frequent cleaning.

Other dairy processing factors which impact waste characteristics are:

- Dilution of waste as a result of wash water utilised (volume)
- Pre-treatment efficiency
- Cleaning chemicals used, concentration and frequency
- Age and condition of the asset

3. Review of Wastewater Disposal Routes and Discharge Requirements

3.1 Overview

This section outlines dairy wastewater / effluent disposal routes and guidelines governing the discharge. Trade waste charges in various regions are summarised, and for comparison, examples of trade waste charges incurred at two sites calculated.

3.2 Disposal routes

3.2.1 General

The treatment requirements of dairy processing wastewater will be determined by the ultimate disposal route or end use of the used water. Disposal routes include:

- Discharge to sewer
- Discharge to surface water
- Irrigation to agricultural land
- On-site reuse (non-process, e.g., hosing down purposes, truck washing, process water cooling and toilet flushing)

The most sustainable disposal route and associated level of treatment will, to a large extent, be governed by the location of the facility. Location of the facility will dictate; a) the space available for treatment infrastructure, b) availability of discharge options, c) discharge-related costs and d) state based environmental regulations.

National and State based guideline documents should be consulted as they provide useful guidance on effluent discharge targets as well as effluent management requirements such as monitoring and reporting.

- National Water Quality Management Strategy paper 16b, Wastewater Management Guidelines for Dairy Processing Plants, 1999
- Victoria EPA Environmental Guidelines for the Dairy Processing Industry, June 1997
- New South Wales EPA Environmental Guidelines for the Use of Effluent by Irrigation, 2004
- South Australian Reclaimed Effluent Reuse Guidelines (Department of Human Services and Environmental Protection Agency, Government of South Australia), April 1999
- Water Quality Protection Note 12, Dairy Processing Plants (Government of Western Australia, Department of Water), November 2012
- Guide to the Environmental Impact Assessment Process in the Northern Territory, March 2014
- Farm Dairy Premises Effluent Management Code of Practice (Tasmanian Dairy Industry Authority), May 2010

A brief discussion of the various disposal routes and typical quality and treatment requirements is presented below.

3.2.2 Discharge to sewer

Where feasible, discharge of wastewater to sewer is often considered an attractive option as it principally reduces the business risks associated with wastewater management and disposal. Disposal of wastewater to sewer is regulated by local councils or local water authorities (who operate and maintain the sewerage system) and requires a permit for discharge.

The feasibility of the sewer disposal option is dependent on the following:

- Location and availability of sewer connection to accept discharge
- Wastewater characteristics permitted for discharge, which informs the level of treatment required

The benefits to industry when discharging to sewer is to remove a regulatory and operational load, whilst outsourcing the treatment and disposal to the local water authority who are specialists in operating treatment plants.

Trade waste discharge does, however, involve costs to an industry – the extent of which depends on the need for the water authority to upgrade facilities and extra operating costs they might incur in accepting the waste stream. Typically, there will be a “headworks charge” (capital contribution) if the systems require augmentation due to industry connection. There will also be an on-going charge for volume and load (usually COD/ BOD, TSS, FOG). Many authorities may also charge a fee based on the nutrient, sulphate and TDS loads of the wastewater.

The requirements for discharge to sewer are set out in a trade waste agreement between the facility and the operating authority. The requirements will be determined by available or planned systems’ capacity for the receiving sewers and treatment plant.

As a guide, typical trade waste effluent quality standards for discharge to sewer are shown in Table 2 below and trade waste charges for a selection of water authorities are presented in Table 3. Trade waste charging regimes may vary depending on the volume and quality of the wastewater discharge to sewer in different regions.

As a rule, partial treatment (pre-treatment) for discharge to sewer is common practice and as a minimum this typically involves flow equalisation followed by FOG removal. The latter is typically achieved via a grease trap, induced air flotation or dissolved air flotation with coagulant addition. This will be followed by anaerobic and / or aerobic treatment, in the event that additional treatment is required to, for example, further reduce organic load discharged.

Table 2 Typical Trade Waste Quality Targets

Parameter	Units	Trade Waste
BOD	mg/L	600 – 1,000
SS	mg/L	500 - 600
FOG	mg/L	100 - 150
Total N	mg/L	200
Ammonia	mg/L	60
Total P	mg/L	50
TDS	mg/L	2,000
E.Coli	org/100mL	-
Temperature	°C	38

Table 3 Typical Trade Waste Charges

Trade Waste Tariff	Units	SA Water – 2016 (SA)	Barwon Water - 2015 (Geelong, VIC)	City West Water - 2016 (VIC)	South East Water - 2016 (VIC)	Yarra Valley Water – 2016 (VIC)	Goulburn Valley Water (All Water Districts Category 3) - 2016 (VIC)	Sydney Water - 2016 (NSW) (Discharging to primary WWTP)	Brisbane Water – 2015 (QLD)
Volume	$/kL	0.16	1.88	0.9573	0.9114 (Above 1 ML/y)	1.0475	0.7778	Quarterly fee	0.95
COD	$/kg	-	0.25 (Above 1200 mg/L)	-	-	-			
BOD	$/kg	0.263 0.396 (Above 1,000 mg/L)	-	0.9747	0.9008 (Above 600 mg/L)	0.8359	0.5182 (Above 600 mg/L)	0. 285 + (0.123 x BOD / 600)	0.93
SS	$/kg	0.233 0.337 (Above 500 mg/L)	0.19(Above 500 mg/L)	0.5281	0.5051 (Above 600 mg/L)	0.4865		0.517	.85
TDS	$/kg	1.32 (Above 600 mg/L)	-	0.0191 (Inorganic TDS)	-	0.0348 (Inorganic TDS)			
TKN	$/kg	0.41	0.77 (Above 60 mg/L)	1.8757	1.9787 (Above 50 mg/L)	1.4044	0.7778 (Above 150 mg/L)		2.12
TP	$/kg	1.997					2.0747 (Above 20 mg/L)		1.68
Sulphur	$/kg		1.03 (Above 50 mg/L)	-	-	-			
Grease	$/kg							1.467	

Trade Waste Tariff	Units	SA Water – 2016 (SA)	Barwon Water - 2015 (Geelong, VIC)	City West Water - 2016 (VIC)	South East Water - 2016 (VIC)	Yarra Valley Water – 2016 (VIC)	Goulburn Valley Water (All Water Districts Category 3) - 2016 (VIC)	Sydney Water - 2016 (NSW) (Discharging to primary WWTP)	Brisbane Water – 2015 (QLD)
Temp	°C	<38 (Not to be exceeded)						$7.138/ML (Above 25°C)	
Sodium	$/kg						0.9188		
pH		6 – 9 (Not to be exceeded)						$ 64.468 / ML (<pH 7)	

The load discharge limits and fee for water authorities listed above are a guideline only. Refer to appropriate water authority for current requirements.

The cost associated with trade waste discharge varies according to the quality of waste and site of facility. A dairy manufacturing site in the Goulburn Valley region for instance can incur a trade waste fee of up to $800,000 per annum (for 1 ML/d plant). The biggest portion of the charge is attributed to flow and BOD. For inland locations salinity and in particularly sodium is a concern when disposing to land and this is reflected in a sodium specific trade waste charge. This could eventually be the biggest contributor of trade charges if salinity in effluent is in fact higher than the assumed 500mg/L (typically for effluent reuse inland TDS < 500 mg/L is desirable).

To compare trade waste charges for a dairy facility discharging untreated effluent to that using with anaerobic digestion, a typical effluent quality has been adopted (as noted in Appendix C) and resulting trade charges calculated. For this example, implementation of pre-treatment applying anaerobic digestion for dairy (1 ML/d WWTP) in Goulburn Valley Water area of operations will result in trade waste charge reduction of around $380,000 per annum. This excludes any costs associated with operating and maintaining the anaerobic digester nor does it include any cost benefits associated with biogas utilisation.

For a similar plant capacity located in South East Water region, untreated effluent trade waste would increase by 75% (to a total of $1.4M per annum) compared to a site located in GVW. With efficient treatment using anaerobic digestion, a reduction of charges of approximately 40% (to a total of $900,000 per annum) is achievable.

These analyses highlight the direct influent of organic load to amount of trade waste charges payable. More importantly, the comparison shows the scale of savings for a 1ML/d plant. A plant double the capacity can potentially save twice as much.

3.2.3 Discharge to surface water

Discharge of treated water from dairy processing plants in Australia direct to surface water bodies is not common. Treatment requirements for discharge to surface water will be determined by local regulations and would typically involve a high level of treatment with nitrogen and phosphorous removal and salt reduction. As a guide for inland water ways, nutrient targets in treated wastewater are typically around TN of 5-10 mg/L and TP of less than 0.2 mg/L.

To achieve these targets extensive pre-treatment followed by biological nutrient removal and tertiary filtration will be required. The pre-treatment stage could include anaerobic treatment to reduce the aeration/energy requirements in the subsequent treatment steps.

Biological nutrient removal processes are designed to reduce nitrogen and phosphorous concentrations. Phosphorus can also be reduced by chemical addition. However, biological phosphorus reduction is often preferable as it saves on chemical cost and sludge disposal. Chemical addition can be used successfully as a polishing step in conjunction or following biological treatment.

Where required, salt reduction will add significant cost and generates a brine disposal problem.

3.2.4 Irrigation to agricultural land

Given that the majority of dairy processing plants are located in rural regions, a large proportion (estimated to be >50%) of dairy processing effluent in Australia is applied to agricultural land. However, there has been a growing concern within the dairy industry and regulators about the sustainability of this practice. A key risk associated with the irrigation of agricultural land with dairy wastewater is the build-up of nutrients particularly phosphorous and sodium. The latter can severely impact crop growth and soil permeability. Where possible, a common practice to manage salinity issues is to shandy the high salinity treated dairy wastewater with low salinity water supplied by local district irrigation channels or pipes.

Dairy processing facilities which irrigate to agricultural land typically utilise a series of lagoon treatment systems comprising mechanically aerated, facultative and winter storage lagoons.

Lagoon systems however are not effective in reducing nutrient and salt levels and an irrigation management plan is required to ensure that sustainable irrigation is achieved. This includes selection of appropriate crops to take up nutrients, crop rotation, application of gypsum, shandying of saline water with low salinity irrigation water and other measures.

As a guide, typical industry irrigation effluent targets are:

- BOD < 150 mg/L
- BOD < 30 kg/ha.day
- TN < 250 kg/yr (soil and crop dependent)
- TP < 50 kg/yr (soil and crop dependent)
- Salinity - preferably < 600 mg/L TDS (soil and crop dependent)
- Heavy metals should not exceed a certain criteria (Australian and New Zealand guidelines for fresh and marine water quality Appendix A, Reference 1)

The above are based on general criteria adopted by EPA's for recycled effluent (municipal). However, it should be noted that in some jurisdictions the EPA is accepting higher BOD values e.g., 200 mg/L for dairy wastewaters subject to suitable local soil conditions and provided this does not result in anaerobic conditions and odours. There are many other factors and parameters at play and a discussion of these is outside the scope of this report. For further information, please refer to the appropriate guidelines and reference resources available in your State or Territory.

3.2.5 On-site reuse

On-site reuse is typically limited to condensate recovery for use as boiler feedwater, CIP make up water and wash down water (similar or better water quality to surface water discharge). Although it is technically feasible to treat dairy wastewater to potable quality suitable for unrestricted use, this is not practiced anywhere and is not considered as part of this study.

Table 4 presents waste quality standards for various discharge methods.

Table 4 Typical Effluent Quality Standards

Parameters	Units	Trade Waste	Irrigation (Standard effluent reuse guidelines)	Surface Water Discharge
BOD	mg/L	600	<150	10
SS	mg/L	600	30	10
Total N	mg/L	200	30	10
Ammonia	mg/L	60		1
Total P	mg/L	50	15	0.5
TDS	mg/L	2,000	600	600

3.2.6 Treatment Requirements, Current and Leading practices

The treatment of dairy processing wastewater will largely be governed by the water quality requirements stipulated by its end use.

In general terms, current dairy processing wastewater treatment practices will include a combination of treatment units and steps, depending on the discharge route for the final treated effluent. Current and leading practices are further discussed in Appendix C.

Anaerobic digestion is often one of the first stages of treatment for high BOD wastewaters (which includes dairy) and is discussed in Section 4 below.

4. Anaerobic Digestion Technology Review

4.1 Overview

This section describes anaerobic digestion technologies to treat dairy processing wastewater and presents advantages and disadvantages of each system. Some examples of commercial installations of anaerobic systems in Australia and globally are also provided.

4.2 Background Digestion Theory

Anaerobic digestion is a natural yet complex process involving the degradation of organic compounds in the absence of dissolved oxygen. The first step to the degradation process is hydrolysis of complex compounds (carbohydrates, fats and proteins) to soluble organics (sugars, fatty acids, amino acids). This is followed by a second step known as acidogenesis involving acidogenic bacteria which convert the soluble organics to short chain volatile fatty acids (VFAs, acetic, propionic, butyric, formic acids etc.) plus hydrogen and carbon dioxide. The volatile fatty acids, with the exception of acetic acid, are transformed as part of the third stage, acetogenesis to hydrogen, carbon dioxide and acetic acid. In the final step, methanogenic bacteria then proceed to convert hydrogen and acetic acid to methane (biogas) and carbon dioxide.

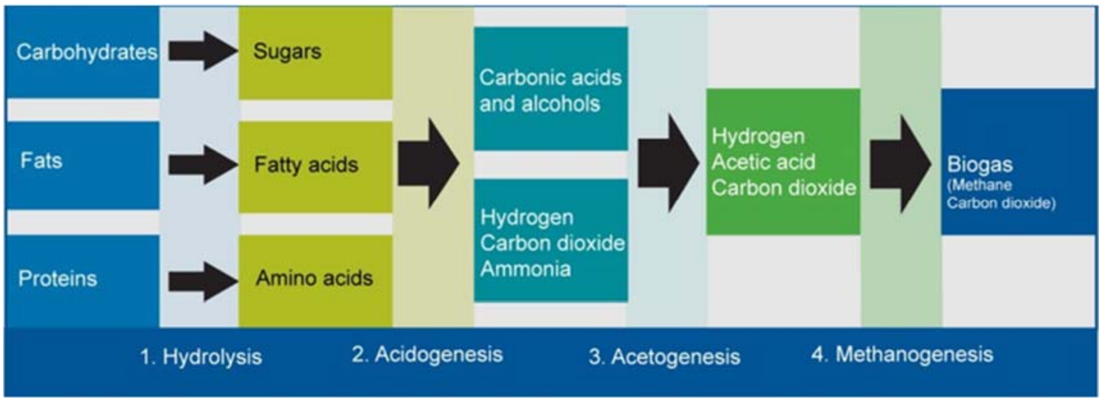

Figure 1 Anaerobic Digestion Pathway

The result of these biological reactions is a reduction in the organic contaminants in the waste stream (BOD, COD, and FOG). The process has little effect on nutrient removal.

4.3 Key Considerations for Successful Operation

It is imperative an equilibrium is established and maintained between VFAs, alkalinity, pH and temperature at all times.

If the first process proceeds at a more rapid rate than the second, then VFAs concentrations will increase. This will result in a reduction of alkalinity which has a follow on effect of rapidly decreasing pH below the optimum range for methanogenic activity.

Methanogens prefer a specific condition to thrive in, with conditions out of the range impacting on organic load reduction and maximum methane capture. For example, methanogens favour nearly neutral pH conditions; condition below pH 6.6 decreases the rate of methane production while the adverse impact is greater for pH above 8.0.

Alkalinity of the wastewater functions to provide buffering capacity and narrows down the range of pH instability. This is particularly important during cleaning regimes at the dairy where acidic solutions are introduced into the wastewater in batches.

Temperature also plays an important role by enhancing the rate of formation of methane. Anaerobic digestion can occur in three temperature ranges, psychrophilic (ambient - 20°C), mesophilic (24°C - 45°C) and thermophilic (45°C - 60°C). Anaerobic digestion in the psychrophilic range is not commonly used for the treatment of industrial wastewater (including dairy)

As a general rule, anaerobic digestion in the mesophilic temperature range is the most common. (optimum of 45°C). The higher temperature promotes bacterial activity and increases the reaction kinetics and the conversion of organics to methane, thus effectively reducing the reactor volume required. Digester temperature beyond optimum values decrease bacteria growth rapidly and ultimately causes bacteria die-off (50°C for mesophilic and 70°C for thermophilic).

Dairy processing wastewater streams are typically warm (around 40°C) which lends itself for anaerobic treatment in the ideal temperature range.

Feed lower than 10°C should be avoided as it inhibits bacteria activity and digestion ceases to function below about 15°C (mesophilic) and 20°C (thermophilic).

Typical rate limiting characteristics of anaerobic microorganisms are provided in Table 5.

Table 5 Anaerobic Digestion Operating Range

Parameter	Units	Optimum Range [4]	Extreme Range [4]
Temperature	°C	30 – 35	25 – 40
pH	-	6.6 – 7.6	6.2 – 8.0
Alkalinity	mg/L as $CaCO_3$	2,000 – 3,000	1,000 – 5,000
Volatile Fatty Acids (VFA)	mg/L as acetic acid	50 – 500	2,000

4.4 Drivers for Anaerobic Treatment

The drivers for implementing anaerobic treatment are often a combination of several factors. In reviewing some of the case studies, it is apparent that selection of anaerobic treatment may be driven by the following factors:

- High trade waste discharge fees
- High electricity/gas costs
- High waste strength (and associated odour)
- Potential carbon credits from capturing methane
- High renewable energy production incentives
- Government co-funding.

4.5 Review of Anaerobic Digestion Options

4.5.1 Overview

Anaerobic digestion systems can be categorised on the basis of hydraulic retention time (HRT), solids retention time (SRT) and/or organic loading rate. Typically, a minimum SRT of 10-15 days is required. For low rate systems the HRT= SRT but high rate systems decouple the SRT from HRT by maintaining anaerobic bacteria in the treatment tank. This is typically achieved through,

- Growing bacteria in a rapid settling granule
- Growing them on a fixed film media or
- Using baffles or membranes or recycling to retain them in the reactor.

As a broad guide anaerobic digestion systems fall into the following categories (shown with indicative hydraulic retention times):

- Anaerobic lagoon systems (20-40 HRT);
- Conventional constructed reactor systems (15–20 HRT);
- High rate anaerobic systems (1-2 HRT).

Anaerobic lagoons involve long detention time and high volumetric requirements. High rate systems were developed to try to overcome these disadvantages for locations with limited space. By increasing the rate at which digestion of the organic material occurs, the detention time required within the digestion system decreases, thereby reducing digester volume requirements and overall footprint. Higher rate systems are therefore significantly more compact than lagoons although it should be noted that installations may be up to 15m tall, so have a high visual impact.

Unfortunately, many high rates systems, despite their smaller footprint, are not suitable to dairy processing wastewater without prior removal of high solids and / or FOG content. High rate systems rely on easy passage of highly soluble waste compounds through the granular medium to enable appropriate contact with the biomass. High fats and solids, if not removed, will interfere with that operation and lead to a highly unstable operating regime (high VFA's and potentially ultimate failure of the anaerobic process).

There is a wide range of proprietary anaerobic systems available on the market, which can be confusing as to the capability and process limitations of the system. While some new systems may have been trialed at pilot scale, actual operating conditions and effluent targets are not representative of results for every dairy waste stream.

Given that there is always a process risk when adopting any treatment, system for implementation, it is recommended that only technologies that are currently installed (and operating successfully) be further explored. The list of these proven systems and short description of each technology is provided in the following section.

Table 6 Known Anaerobic Digestion Categories Applied to Dairy Processing

Systems	Anaerobic Digestion Technology	Location Applied
Anaerobic Lagoon Systems	Uncovered Anaerobic Lagoons (AL)	Asia
	Covered Anaerobic Lagoons (CAL)	Australia/USA/China
Conventional Systems	Constructed above ground digestion tanks (mixed or plug flow)	World wide
High Rate Systems (Engineered)	Anaerobic Flotation Reactor (AFR)	US, Europe
	Upflow Anaerobic Sludge Blanket (UASB)	Limited

Systems	Anaerobic Digestion Technology	Location Applied
Emerging Systems	Anaerobic Membrane Bioreactor (AnMBR)	NA

4.5.2 Uncovered Anaerobic Lagoons (AL)

Traditional uncovered anaerobic lagoons are more common than covered lagoons in a number of industries (which is really a reflection of the age of the facility and costs associated with covers - the advent of HDPE covers only being a relatively recent application). Generally, the FOG which are present in the dairy processing wastewater accumulate to form a layer, creating a natural cover, which controls odour to some extent. This method is cheaper, requires less maintenance than CALs and is a well-established and widely used method. However, no gas recovery potential is realised. Dependent on the concentration of fats and the industry type, a fat layer cover can take months to form and initial odours can be an issue, until crust formation. It should be noted that modern practice for dairy wastewater does not generally include uncovered lagoons for the above reasons.

Figure 2 Uncovered Anaerobic Lagoon (Juice factory)

4.5.3 Covered Anaerobic Lagoon (CAL)

The Covered Anaerobic Lagoon (CAL) comprises a lagoon system with a purpose built cover over the entire surface area which captures the biogas, eliminates odours and assists somewhat in reducing heat loss. The term CAL is often interchangeable with the term HRAL which stands for a High Rate Anaerobic lagoon. The term HRAL was first coined in the mid 90's and specifically referred to a compact two compartment covered anaerobic lagoon, often containing recycle streams and sludge extraction systems. The aim was to introduce better contact between biomass and waste to reduce the retention time. The first compartment would be designed to contain a sludge layer up to several metres thick. The feed would be introduced at various locations at the bottom of the lagoon to maximize contact between the incoming feed and the active anaerobic biomass. Biomass carried over into the second compartment would settle out and some systems where designed to extract the settled sludge in situ and return this to the first compartment. This system was typically designed around a hydraulic retention time of 6 to 10 days as distinct from systems which were designed to achieve 12-20 days' retention.

To avoid confusion for the reader, given the subtle differences, in this document the more generic term CAL will be used to mean also a HRAL or other similarly covered anaerobic lagoons.

Figure 3 Covered Lagoon (Biodiesel Plant)

4.5.4 Constructed Digestion Tank Reactors

Constructed Anaerobic Digestion systems typically comprise concrete or steel tanks (insulated) and are maintained at a constant elevated temperature and use either a motor-driven mixer, a liquid recirculation pump or compressed biogas to ensure mixing [5]. The elevated temperature (nominally at mesophilic range of 30 – 40^{o}C) and high mixing rates increase the rate of digestion and breakdown of influent organic material. However, this system has higher construction and maintenance costs than CAL systems, due to the more complex construction and mechanical (boilers, heat exchangers, pumps and mixers) and electrical equipment requirements. The digesters, which incorporate an enclosed roof to collect the generated biogas, are often referred to as continuously mixed reactors.

Figure 4 Constructed Reactor (USA)

There are variations to the complete mix systems including plug-flow digesters, which involve long, narrow tanks with a gas tight cover used to capture the biogas [5]. The waste slurry enters one end of the tank and exits the other, being forced along by waste entering in the ”plug” behind it. Plug flow reactors are generally regarded as better suited for high solids slurry type wastewaters and so are not typically used for dairy manufacturing application.

There are numerous proprietary digester tank systems (mainly in Europe and USA) based on conventional arrangement (longer detention time), but with differing covers, construction or mixing systems.

Figure 5 Constructed Reactor (Valbio)

ADI-BVF® Anaerobic Reactor

The reactor is a proprietary low rate system, offered in two configurations, either partially in-ground concrete / earthen basin or above ground concrete/steel tank where space is a constraint.

Depending upon trade waste limits, the reactor may also include internal gas-liquid-solids separators to produce low effluent TSS concentrations.

A sludge recirculation returns digester effluent to the influent via internal heater-laterals and external pumping. Generally, stabilised sludge is wasted once or twice a year.

A floating geomembrane (cover over the digester) is employed to collect and store biogas.

Figure 6 Above Ground Constructed Digester (sourced from ADI®)

4.5.5 Anaerobic Membrane Bioreactor (AnMBR)

The anaerobic membrane bioreactor is sometimes referred to as an anaerobic mixed batch reactor. Membrane bioreactor technology combines the biological degradation process with a direct solid–liquid separation by membrane filtration. By using micro filtration membrane technology (with pore sizes ranging from 0.05 to 0.4 μm), MBR systems allow the complete physical retention of bacterial flocs and virtually all suspended solids within the bioreactor [6]. Due to the nature of the membranes, frequent chemical cleaning may be required for when fouling occurs (blockage of membrane pores).

Some AnMBR have been reported to accept fatty wastes, although there are no commercially available installations in dairy manufacturing sites in Australia and internationally.

4.5.6 Proprietary Anaerobic Digestion Systems (High Rate)

There are many proprietary purported high rate anaerobic digestion systems on the market. Some examples are presented below. This is not exhaustive and there are other suppliers who provide similar technologies with slight variations. Most of these systems either rely on high sludge recirculation and not all are suitable for dairy processing wastewater

While several suppliers have apparently implemented systems at dairy wastewater sites, it should be noted that details of pre-treatment and operational performance are somewhat scant. As noted above, high rate systems are regarded as having limited application to typical dairy wastewaters due to the grease content, although may be applicable if the grease has been removed upstream.

Anaerobic Flotation Reactor (AFR)

The Hydrothan system, developed in Europe by HydroFlux, involves an external sludge recirculation vessel. The technology is suited to treating wastewater containing fats, oils, and greases (FOG) and/or biodegradable solids such as proteins and starch. The reactor design allows for a higher organic loading rate (compared with conventional anaerobic digestion) and a taller reactor tank (some 15 metres) results in a smaller footprint than conventional anaerobic digestion. A schematic of the reactor is shown in Figure 7.

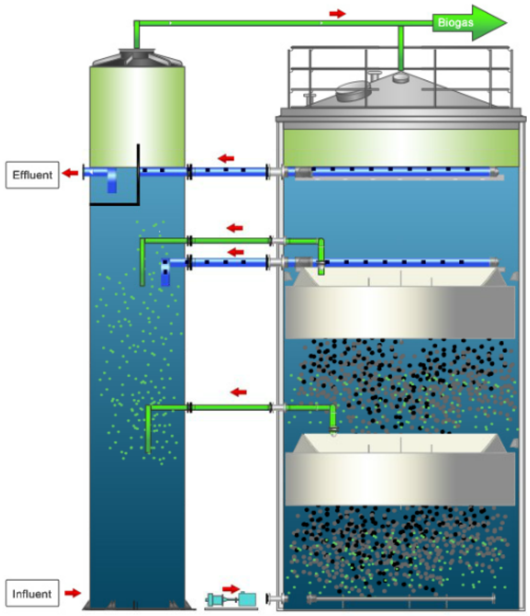

Figure 7 Hydrothan Digestion and Recirculation Vessel System

The Biopaq® AFR reactor shown in Figure 8 has recently been developed by Paques BV in the Netherlands. The AFR provides good mixing of the wastewater with the granular sludge in the bottom of the reactor (1). Most of the conversion and biogas production occurs in zone (2), with the biogas collected via the lower level stage separator (3). This causes a lift which forces the water upwards through the riser tube (4), to the gas separator at the top of the reactor (5). The biogas exits the reactor at the top and the water returns to the bottom of the reactor via the downcomer (6), hence the name internal circulation. In the second upper compartment (7) the effluent is polished and biogas produced here is separated in the upper level stage separator (8). The effluent leaves the reactor from the top.

This type of system also includes digesters with outflow passed to an external Dissolved Air Flotation (DAF) tank which thickens and recirculates the sludge back to the reactors. Proprietary systems have been developed and marketed by Nijhuis industries (Netherlands), Global Water Engineering (Flotamet).

Some international installations of established process and applied to dairy processing wastewater are provided in Table 9.

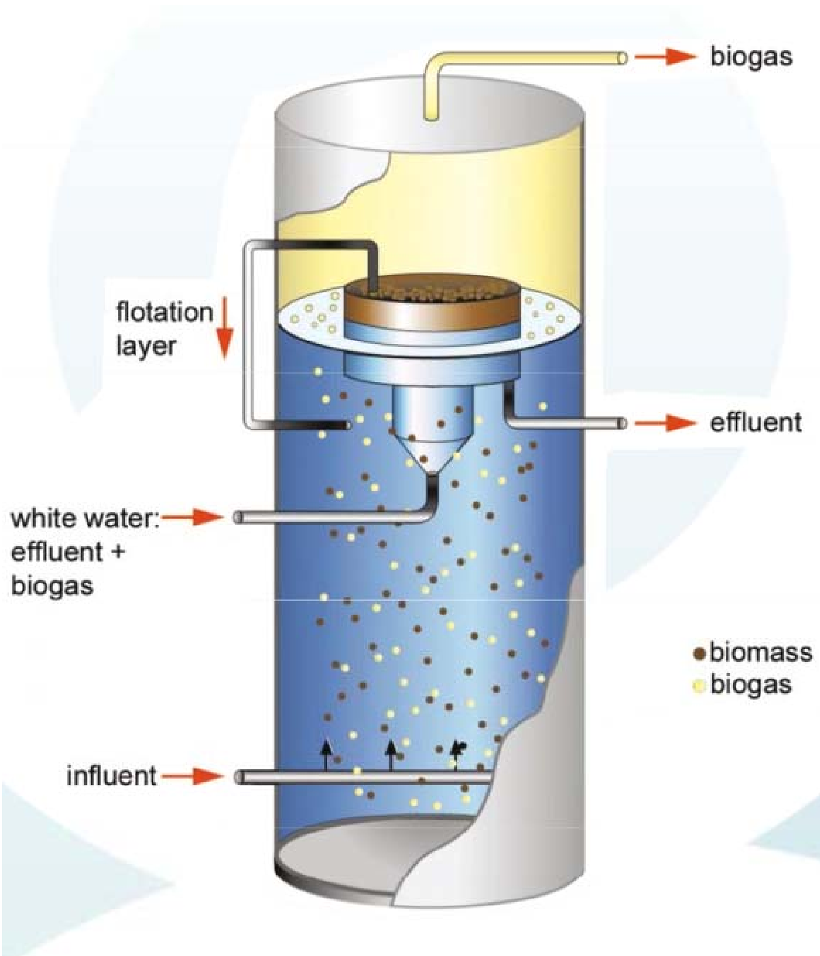

Figure 8 Paques BIOPAQ® AFR Reactor

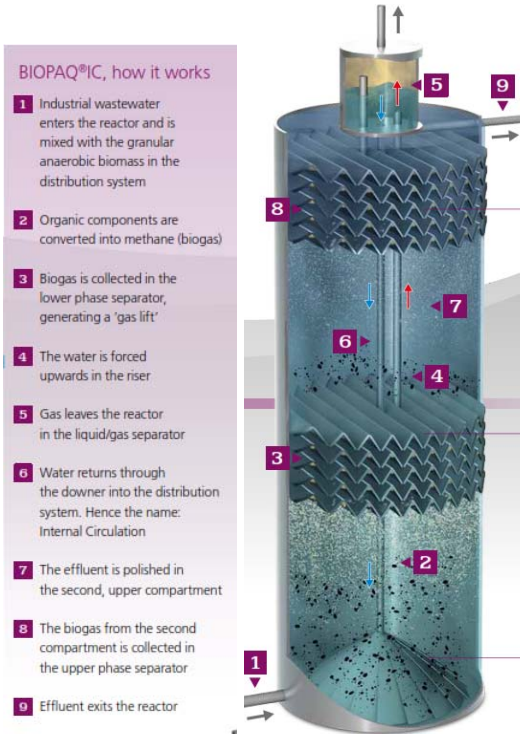

Figure 9 Paques BIOPAQ® IC Reactor

Upflow Anaerobic Sludge Blanket (UASB)

In up-flow anaerobic sludge blanket reactors, the influent enters at the bottom of the digester, flows upward through a compact layer of bacteria (the sludge blanket) and exits at the top of the reactor [7]. As the gas forms (produced by anaerobic digestion) it flows upwards transporting particles towards the top of the reactor, however as the gas passes through the sludge blanket these particles are trapped.

These compact reactors may be up to 15m. Operationally, UASB systems require close supervision of granulation and scum accumulation in the reactors when excessive loading can lead to problems, hence a good fat separator prior is necessary.

UASB is not applicable to dairy wastewater unless good fats / solids removal is in place.

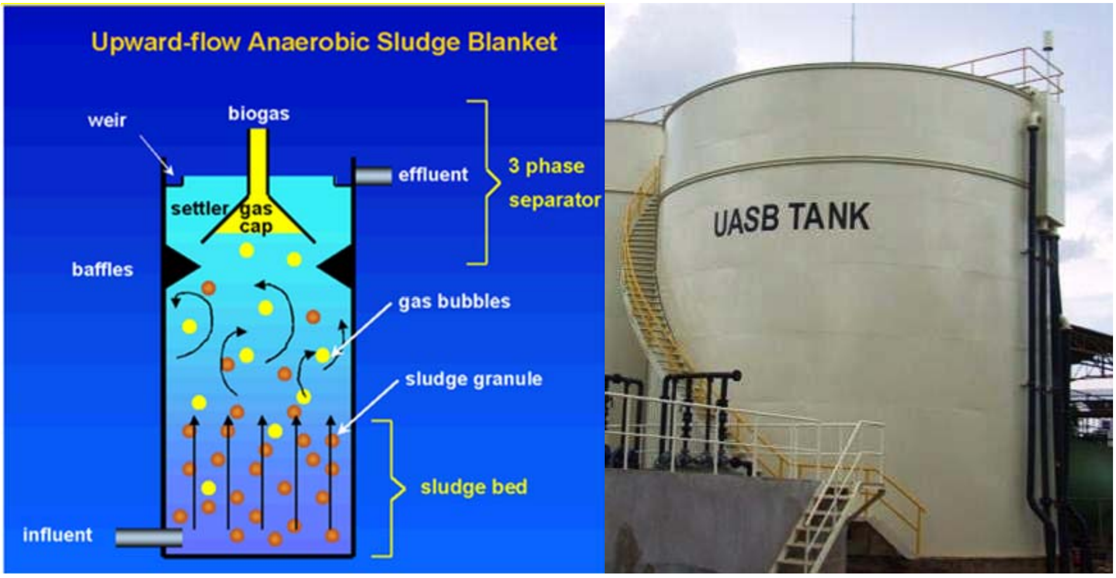

Figure 10 UASB Process and Installation [8]

4.6 Summary of Comparison

Table 7 Comparison of Anaerobic Digestion Systems – Potentially Applicable to Dairy Industry

Component	Uncovered Anaerobic Lagoons (AL)	Covered Anaerobic Lagoon (CAL)	Constructed Digestion Tank Reactors	Proprietary Anaerobic Digestion (General)	Anaerobic Flotation Reactor (AFR)	Upflow Anaerobic Sludge Blanket (UASB)	Anaerobic Membrane Reactor (AnMBR)
✗ - Disadvantage / Unable to achieve, ✓ - Advantage / Ability to achieve, ✓✓ - Advantage / High ability to achieve							
Process							
Influent limitations (mg/L)	NA	NA	NA	8,000 – 70,000 mg/L COD (FOG 50% of COD concentration)	8,000 – 70,000 mg/L COD (FOG 50% of COD concentration)	500 – 1,500 (SS & FOG), can handle high soluble BOD	500 – 1,500 (SS & FOG)
Volumetric loading rate (kg COD/ m^3.day)	0.02 – 0.8	0.05 – 0.8	1 - 5	7 - 9	7 - 9	7 - 9	6 - 10
HRT retention time (days)	20 – 50	15 - 40	10 - 30	8 – 15	1 - 2	1 - 2	1 - 2
SRT retention time	20 – 40	20 - 50	20 - 50	>50	>50	>50	>50
BOD/COD removal rates (%)	50 - 80	60 - 90	65 - 90	50 – 90	50 - 85	50 - 85	50 - 85
Digester temperature (°C)	Ambient	Ambient or Mesophilic (24 – 40)	Mesophilic (24 – 40) / Thermophilic (45 - 60)	Mesophilic (24 – 40) / Thermophilic (45 - 60)	Mesophilic (24 – 40) / Thermophilic (45 - 60)	Mesophilic (24 – 40) / Thermophilic (45 - 60)	Mesophilic (24 – 40)
Ability to handle high suspended solids	✓	✓	✓✓	✓✓	✓	✗	✗
Ability to handle fatty streams	✓	✓	✓	✓	✓	✗	✗
Ability to achieve high organic reduction	✗	✓	✓✓	✓	✓	✓	✓✓
Low detention time	✗	✗	✓	✓	✓✓	✓✓	✓✓
Ability to offset high peak loads	✓	✓	✓	✓	✓	✓	✓
Minimal odour issues	✗	✓ [1]	✓	✓	✓	✓	✓

Component	Uncovered Anaerobic Lagoons (AL)	Covered Anaerobic Lagoon (CAL)	Constructed Digestion Tank Reactors	Proprietary Anaerobic Digestion (General)	Anaerobic Flotation Reactor (AFR)	Upflow Anaerobic Sludge Blanket (UASB)	Anaerobic Membrane Reactor (AnMBR)
Recovers biogas	✘	✓	✓	✓	✓	✓	✓
Mixing requirements	✘	✘	✓	✓	✓	✓	✓
Consistent effluent quality	✘	✘ 2	✓ 2	✓	✓	✓	✓✓
Ability to retain heat in winter	✘	✘	✓✘	✓ 3	✓ 3	✓ 3	✓
Well established, widely used in the dairy manufacturing industry (Australia)	✘	✓	✓	✘	✘	✘	✘
Well established, widely used in the dairy manufacturing industry (Internationally)	✘	✓	✓✓	✓✓	✓✓	✘	✘
Operation / Maintenance							
Short startup time	✓	✓	✓	✓	✓✘	✘	✘
Simple to operate / requires less operator attention	✓✓	✓	✓	✓	✘	✘	✘
Float removal required	✘	✓	✓	✓	✘	✓	✘
Desludging required	✓	✓	✓	✘	✘	✘	✘
Cost							
Capital cost	Low	Low 5	Medium - High	Medium - High4	Medium 4	Medium 4	High
Operating cost	Low	Low	Medium	Medium	High	High	High
Other components							
Footprint requirement	High	High	High	Low	Low	Low	Medium
Profile of equipment	Low	Low	Low	High	High	High	Medium

Notes:

1. If sealed properly
2. Subject to seasonal variation
3. Heat exchanger system usually in place
4. Due to inclusion of heat exchanger
5. Refer to Table 13 for cost breakdown

4.7 Installed Anaerobic Digestion Technology in Dairy Processing Industry

Several examples of dairy manufacturing waste treatment plants in Australia and globally are presented for a general indication of processes installed.

4.7.1 Australian Experience

Table 8 Identified Australian Installations

Location	AD used	Capacity	Dairy Products Produced	Pre/post-treatment	Other	Install Year
Lion Cheese Factory, Burnie, TAS	Constructed digestion tank reactors (Low rate anaerobic)				Floating membrane cover system	2015
Lion Dairy and Drinks, Crestmed, Brisbane, QLD	Constructed digestion tank reactors (Low rate anaerobic)	5,500 m^3/day 9,000 mg/L COD 6,000 mg/L BOD 2,800 mg/L TSS 4 – 12 pH 35°C	Flavoured milk	Post-treatment: SBR for aerobic polishing	Increasingly stringent waste disposal requirements >90% COD removal Geomembrane cover used Biogas used to heat boiler for use within the factory, excess gas flared	2012
Richmond Dairies, Casino, NSW	Constructed digestion reactors – above ground	20 - 180 m^3/day	Frozen milk products, specialty powder, and bulk liquid milk products.	Post treatment with SBR	Existing system could not meet increasing stringent disposal requirement. Odour an issue (within 50m of residential area) High cost of DAF dosing Treated waste reused for land irrigation at nearby gold course	2009
Tatura Milk Industries (TMI), Tatura, VIC	CAL with biogas capture	4,000 m^3/day 2,600 mg/L COD 38°C	Cream cheese, nutritional powders, lifestage powders, milk and	Screening, balancing tank	The biogas is captured and cleaned as the fuel source for cogen system. Energy is fed into the national grid.	2002 (covers installed)

Location	AD used	Capacity	Dairy Products Produced	Pre/post-treatment	Other	Install Year
			milk products and milk powders			2007 (Cogen)
Devondale - Murray Goulburn Cooperative Co. Limited, Leongatha	Constructed digestion tank reactors (Low rate anaerobic)	4,000 m^3/day 6,500 mg/L COD 4,000 mg/L BOD 1,300 mg/L TSS 500 mg/L FOG >300 mg/L N	Milk, cream, butter, spreads, yogurt and cheese	Pre-treatment: Equalisation tank with mixing and DAF Post-treatment: SBR	85% COD removal 10,900 m^3/d biogas generated	2005
Leitchville	Constructed digestion reactors – in ground lagoon (Low rate anaerobic)					1998
Warrnambool Cheese and Butter, VIC	Constructed digestion reactors – in ground lagoon (Low rate anaerobic)	1,860 m^3/day 25,000 mg/L COD 39,300 m^3 lagoon	Cheese, milk powders, whey proteins concentrate, butter, cream and packaged milk		85% COD removal 88% BOD removal 50% TSS removal 28,800 m^3/d biogas generated Operates at 30°C 21 HRT Lined with geomembrane fabric Geomembrane cover used	1993

4.7.2 International Experience

Table 9 International Installations of Anaerobic Digestion Technologies

Location	AD used	Capacity	Dairy Products Produced	Pre/post-treatment	Other
R&R Ice Cream, Leeming Bar, North Yorkshire, UK	Waste transferred to a nearby constructed digester facility funded by Iona and operated by Veolia	1,500 m^3/day	Ice cream, sweets and frozen yoghurt in many different formats including tubs, cones, bars, desserts, stick products and ice cream sandwiches		Completed 2015 Produces 550 Nm^3/hour of b The heat produced by the combined heat and power system is used to produce hot water for the site as well as steam which is used for general cleaning purposes. Decision to install CHP due to rising demand for power.
First Milk, Cumbria, UK	Constructed digester	1,650 m^3/day of process effluent and whey	Cheese	Aerobic polishing	**Driver:** Existing aerobic plant unable to meet new tighter discharge limits AD installed 2015 Produces 1,000 Nm^3/hour of biogas and generates 5.35 Megawatt hours (MWh) Methane concentration of at least 55% Revenue benefits will include 20-year index-linked, government-backed incentive (FiT and RHI) payments.
Dairygold Co-Operative Society Limited, Mitchelstown, Co. Cork, Ireland	Above-ground 45,000 m^3 proprietary low-rate anaerobic (ADI-BVF) Two heat exchangers are	5,500 m^3/day 2,850 ppm COD 1,560 ppm BOD 700 ppm TSS 1.7 – 12.9 pH	Whole, skim, and buttermilk powders; milk proteins; butter (salted, unsalted, and lactic); cheese and cheese powders;	Polishing with BNR system	**Driver:** Periodic overloading of pre-existing biological nutrient removal (BNR) plant and odour issues Effluent: 5,500 m^3/day 200 ppm COD 40 ppm BOD

Location	AD used	Capacity	Dairy Products Produced	Pre/post-treatment	Other
	used to capture heat from the effluent and transfer it to the influent before it enters the reactor		and a variety of whey products		160 ppm TSS 6.5 – 7.9 pH 29°C Reactor covered with a floating geomembrane cover A portion of the biogas is used in a dual-fuel boiler to produce hot water to heat the reactor. The remaining portion of the biogas is used for supplementing heating requirements in a plant boiler or burned in a waste gas flare
Valley Queen Cheese Factory, Milbank, South Dakota, USA	Above ground 8,300 m^3 proprietary low-rate anaerobic (ADI-BVF)		Reduced- and low-fat cheddar and marbled Colby-Jack cheese.	1,890 m^3 twin-tank sequencing batch reactor as polishing step	**Driver:** To meet more stringent effluent regulations Treated effluent discharges into the Whetstone Creek and ultimately ends up in the Minnesota River.
HP Hood LLC, Winchester, Virginia, USA	Above ground proprietary low-rate anaerobic New 12,800m^3 (ADI-BVF) reactor to work in parallel with an existing 4,500m^3 (ADI-BVF) reactor		Fluid dairy and non-dairy beverages using ultra-high-temperature (UHT) and extended-shelf-life (ESL) technologies	New 3,700m^3 ADI-SBR (retrofitted from an existing 3,700m^3 ADI-BVF)	**Driver:** Upgrade to cater for increase in production and ensure that the pretreated water discharged from the plant to the local sewer will meet the discharge limits for BOD and TSS.
Cayuga Milk Ingredients, Auburn, New York	Constructed digester	950 m^3/d and 95 m^3/d (whitewater)	Pasteurized cream, whole milk powder, liquid permeate,	Effluent is treated with conventional aerobic treatment	80% COD removal 85% BOD removal

Location	AD used	Capacity	Dairy Products Produced	Pre/post-treatment	Other
		6,000 kg/day COD	condensed milk, skim milk powder, non-fat dry milk and milk proteins	followed by a DAF for solids separation.	Biogas used partially to heat up the wastewater in order to ensure optimal anaerobic digestion Production of up to 1,900 Nm^3/d (at 75% CH_4) of biogas, with an energy content of 590 kW.
Strauss Dairy, Misgav, Israel	Proprietary low-rate anaerobic (ADI-BVF)	1,500 m^3/d 11,200 ppm COD 25 – 35°C	Cheese, yogurt, and flavored milk drinks		**Driver:** Required reliable treatment of its process wastewater, and it also saw potential to recover green energy from anaerobic treatment Effluent quality of 750 ppm COD and 300 ppm SS Reactor covered with geomembrane cover system Biogas used in plant boiler. Biogas production replaces 30% of condensed hydrocarbon gas required for heating the steam boilers
BV Dairy, Dorset, UK (Demonstration plant)	High rate anaerobic systems		Fresh and cultured dairy products, Yoghurt and soft cheese		Installed 2011 Built with finance from the Environmental Transformation Fund (ETF), administered by WRAP (Waste & Resources Action Programme), as part of a Government initiative to stimulate innovative Anaerobic Digestion (AD). Uses a combined heat and power engine to convert biogas and exported to national grid

Location	AD used	Capacity	Dairy Products Produced	Pre/post-treatment	Other
Ben and Jerrys, Hellendoorn, Netherlands	AFR	200 m^3/day 4,400 kg/day COD (max) 2,900 kg/day COD (avg)	Ice cream, milk, cream, fruit	To sewer	90-95% COD removal 3.5 days HRT 50 – 100 days SRT H_2S scrubbed with THIOPAQ, quality. CH_4 70%, H_2S <25ppm. Biogas produced used in boilers to heat process water
Kraft Beaver Dam, USA	BIOPAQ UASB	19,000 kg/day COD	Cream cheese		Biogas used to generate electricity for national grid
Anchor Products, NZ	BIOPAQ IC reactor (UASB)	6,110 kg/day COD	Multiple products	DAF, aerated lagoon	
Gagangiri Milk Products, India	BIOPAQ UASB	450 kg/day COD			
Alpura, Mexico	BIOPAQ IC	12,180 kg/day COD			
ROTR Co-Operative Creamery	BIOPAQ IC	4,350 kg/day COD			
Mumu Alimentos, Brazil	BIOPAQ IC	3,235 kg/day COD			
Vivartia, Cyprus	BIOPAQ IC	3,200 kg/day COD			
Ecker Dairy, Turkey	BIOPAQ IC	9,000 kg/day COD			
Emmi Milch, Switzerland	BIOPAQ IC	2,800 kg/day COD			
Danone, Russia	BIOPAQ IC	4,300 kg/day COD			

It is evident from available information, that numerous overseas dairy processing sites employ high rate anaerobic treatment systems whereas in Australia low rate systems are more prevalent. The key reason for this is that the majority of dairy processing facilities in Australia are in rural areas and have space to employ lagoon treatment or conventional constructed systems and land irrigation of treated effluent. For a few overseas examples, high rates systems (although not typical) have been installed. While information is scant on pre-treatment and performance, it can only be surmised that significant fats / grease have been removed prior to treatment in the high rate digester.

Other examples of anaerobic digestion technologies used in other industries are provided in Appendix B.

5. Covered Anaerobic Lagoon Design Criteria

5.1 Outline

This section outlines the wastewater characteristics, monitoring requirements and summary of design criteria for the CAL systems and associated costs. As a general rule CAL's have been adopted widely in a number of industries, as they represent a low capital cost option and provide the means of containing odours, while having the ability to generate a useful by-product (biogas).

A more detailed description of the design criteria, considerations that should be incorporated, common pitfalls and typical design values are contained in Appendix E, although a summary appears in Table 11 below.

5.2 Waste Characterisation and Monitoring

In determining the application and operational performance, monitoring of the wastewater and the pond is required, which is discussed below. Monitoring provides parameters on which to base the design, and during normal operations gives an indication of the health and stability of the pond.

As a minimum, a wastewater sampling plan should incorporate parameters outlined in Table 10 below. Frequency of monitoring is largely dependent on variability of production (during the day, week and year), size of the facility, and may involve weekly sampling of parameters (except pH, wastewater flow and gas production which should be daily or online).

Table 10 Wastewater Analysis (Raw and Treated)

Parameter	Unit	Application / Purpose
Flow	kL/d	Design and operational performance
Temperature	^{o}C	Operational control
pH	-	Operational control
FOG	mg/L	"
TSS	mg/L	"
TDS	mg/L	Design
BOD_t	mg/L	Design and operational performance
BOD_s	mg/L	"
COD_t	mg/L	"
TN	mg/L	"
NH_3	mg/L	"
TP	mg/L	"
Sulfate	mg/L	"
Alkalinity	mg/L as CaCO3	Operational control

Parameter	Unit	Application / Purpose
VFA	mg/L	Operational control
Gas production	m^3/d or m^3/kg BOD destroyed	Operational control

The collection of wastewater samples is recommended at the end of the collection / reticulation system pipe (combination of all effluent streams generated from the plant) or equalising tank / sump and sampled at the same location to obtain a representative waste streams. Composite samples and discrete samples over the day may be required to properly characterise the wastewater.

Ideally, the wastewater stream should also be sampled and analysed during cleaning regimes (or other regimes where effluent stream may be overloaded with organics) to ascertain fluctuations of waste parameters.

With a sample plan and sufficient sampling numbers, then the minimum, average and maximum values of the wastewater stream can be characterised.

Without comprehensive wastewater characteristics, the design of any anaerobic treatment systems will potentially be compromised. The wastewater characteristics relays the state of the waste stream, then informs the need for pre-treatment steps and which anaerobic digestion system might be best suited for the application.

Where wastewater stream monitoring is part of the operational practice, then this data will be invaluable in providing better insights to the performance of existing systems (what removal rates are able to be achieved) and how best to optimise operations or augment the system to achieve better removal rates / biogas capture.

Other wastewater characteristics may be required depending on the wastewater. (e.g. volatile solids, calcium, etc.).

5.3 Summary of Criteria

Table 11 CAL Design Criteria

Design Criteria	Unit	Typical Range
Influent characteristics		Temperature: 30- 35°C Alkalinity > 1,500 as $CaCO_3$
Loading rates	kg.COD/m^3.day	0.03 – 0.4
Pond HRT	days	10 – 40
Pond depth	m	5 – 7 (deeper preferred)
Pond freeboard	m	0.5
Pond geometry	Length to width ratio-	2-3 : 1
Pond slope	-	3:1 (sandy soils) 2:1 (clay soils)
Effluent characteristics		pH: 7.0 -7.6 VFA: 50 – 500 ppm as acetic acid Alkalinity: 2,000 – 3,000 ppm as $CaCO_3$ Ratio of VFA / Alk: 0.1 – 0.5

Design Criteria	Unit	Typical Range
		Ratio of VFA / Alkalinity is an important factor.
Biogas generation	m^3 biogas produced per kg COD removed	0.5
	m^3 CH_4 produced per kg COD removed	0.25 - 0.35

Table 12 CAL Key Considerations

Key Issues / Considerations	Examples of Mitigation Strategies
Flow variation	• Equalisation tank
Shock load especially pH spikes	• Equalisation tank to encourage mixing and stabilisation • Multiple inlets for even distribution
Scum accumulation under cover	• Appropriate upstream FOG removal, i.e. IAF and DAF • Introduction of scum breaking mechanism, such as sludge recirculation pipes to surface at corner of ponds
Accumulation of stormwater on cover	• In part due to strong winds hence accumulating rainfall in one section of the cover • Weighted pipe system and proper channels to sump • Sump pump to remove collected water
Ensuring gas pressure under the cover doesn't build up excessively	• Multiple pressure reliefs • Gas pressure for monitoring and control • Ring main or multiple draw off points • Sufficient and sensitive instrumentation
Desludging	• Design to allow for sludge removal without removing cover / taking pond off-line • Multiple draw off points • Small flow and intermittent draw off
Protecting cover from tears and pests	• Consideration of fence • Removal of vegetation from embankments • PE (HDPE, LDPE, LLDPE) • >2 mm thickness • Appropriate cover anchorage
Decrease of biogas production	• Check influent waste stream and operating parameters are within criteria (VFA, Alkalinity, pH)

5.4 Cost Estimates

The indicative cost estimates presented in Table 13 below assumes that the biogas production is 0.35 m^3/COD removed.

Table 13 CAL Cost Estimate

CAL Cost Component	Small Facility	Low - Medium Facility	High – Medium Facility	Large Facility
Nominal Wastewater Flow (kL/d)	500	1,500	4,000	7,000
COD load kg/day	2,000	6,000	16,000	28,000
CAL size, ML	7.5	22.5	60	91
Biogas production, m^3/d	500	1,500	4,200	7,300
Generic cost				
AL excavation, cut and fill	$200,000	$600,000	$1,500,000	$2,300,000
Lagoon liner	$50,000	$150,000	$400,000	$600,000
Inlet and outlet structures	$20,000	$20,000	$35,000	$40,000
CAL cover	$150,000	$350,000	$900,000	$1,400,000
Electrical generator, biogas flare	$250,000	$500,000	$950,000	$1,350,000
Sulphide scrubber	$25,000	$30,000	$40,000	$50,000
Ancillaries, pipework and installation	$400,000	$800,000	$1,400,000	$1,950,000
Sub-total	$1,095,000	$2,450,000	$5,225,000	$7,690,000
Contingencies, design, engineering (30%)	$400,000	$800,000	$1,600,000	$2,400,000
Total	$1,495,000	$3,250,000	$6,825,000	$10,090,000
TOTAL SAY	**$1.5M**	**$3.3M**	**$6.8M**	**$10.1M**

The cost estimates above have been based on industry standard cost for items outlined below:

- $25/$m^3$ for AL excavation, cut and fill
- $25/$m^2$ for lagoon liner
- $60/$m^2$ for CAL cover.

6. Biogas Conditioning Review

6.1 Overview

This section outlines the need for biogas conditioning and technologies to remove contaminants to make the gas usable, as well as providing estimates of associated capital and operational costs and common pitfalls. The potential for use of the biogas (described in Section 7) may, in some cases, be limited to the contaminants contained in the biogas, hence the need for removal.

6.2 Biogas Characterisation

Biogas is a combustible gas created by anaerobic digestion of organic material. It typically contains approximately 65% of methane, 35% of carbon dioxide and traces of other contaminants, as detailed in the table below. For highly proteinaceous wastes, the methane content may often be higher at 70-80%. The table also compares the natural gas criteria.

Table 14 Biogas Characteristics (General and not specific to dairy industry)

Parameter	Formula	Units	Industrial WW Biogas	Natural gas criteria
Methane	CH_4	% vol	45-75	
Carbon dioxide	CO_2	% vol	25-55	
Carbon monoxide	CO	% vol	<0.2	
Nitrogen	N_2	% vol	0.01-5.0	
Oxygen	O_2	% vol	0.01-2.0	≤ 0.2
Hydrogen	H_2	% vol	0.5	
Hydrogen sulphide	H_2S	ppm	5-20,000	≤ 3.8
Ammonia	NH_3	ppm	0.01-3	
Siloxanes		ppm	traces	
Relative humidity		%	100	Dew point ≤0 ^{o}C
Total inert gas		mol%		≤ 7.0
Calorific value		MJ/m^3	15 - 25	37 - 43

Biogas has been used as a renewable fuel in numerous applications, but the trace contaminants such as water vapour and H_2S must be removed before it can be used in some gas appliances, due to the corrosive nature of hydrogen sulphide when combining with water vapour and the low heating value due to the low concentration of methane. Some cogeneration systems can tolerate H_2S up to 500 ppm, but with most facilities some scrubbing is normally required.

Biogas contains a number of contaminants which might interfere with usage, including:

- Carbon dioxide
- Hydrogen sulphide
- Water vapour
- Oxygen
- Siloxane.

6.3 Biogas Conditioning Requirements

As a result of the complex anaerobic digestion process biogas is formed. Some components of the biogas may be harmful and/or corrosive in nature, thereby require conditioning and monitoring to minimise adverse impacts on operators and biogas equipment.

The potential impacts on system performance caused by various biogas contaminants are summarised below [9].

Table 15 Biogas Conditioning and Impacts

By-products	Impacts on System
Hydrogen sulphide (H_2S)	H_2S gas is corrosive in nature, poisonous, foul-smelling (like rotten eggs) and exposure to humans is a dangerous health risk. Exposure to H_2S concentration in excess of 500 ppm is lethal. In the presence of moisture, H_2S reacts to form sulphurous and sulphuric acid, a highly corrosive chemical that adversely impacts biogas equipment and piping.
Water vapour / moisture	Similar to H_2S gas, the presence of moisture promotes corrosivity as contact with carbon dioxide forms carbonic acid. Excessive accumulation of condensate water also creates a possibility blockage of gas pipework (normally lower sections).
Carbon dioxide (CO_2)	CO_2 reacts with moisture to form carbonic acid which is a corrosive solution. Lowers ability to maximise biogas production
Nitrogen (N_2)	Concentration of nitrate in dairy manufacturing sites is fairly low, hence nitrogen gas is present in low values. The issue of nitrogen gas is conversion to nitrous oxygen at high temperature and lowers ability to maximise biogas production.
Oxygen (O_2)	Oxygen concentration should not be present unless due to air ingress. Mixing of oxygen with biogas creates an explosion risk (the higher the volume of air ingress the greater the risk).
Siloxanes	Siloxanes are found in surfactants and when combusted forms microcrystalline silicon dioxide. It tends to leave deposit on surfaces, thereby resulting in abrasion of equipment. Siloxane is volatile and exists in trace amounts. Fortunately, siloxanes are not common in the dairy manufacturing sites as such minimises this risk.
Dust	Dust presents an operational problem as accumulation causes pipe blockages.

In most applications, H_2S and moisture control are key problems and often require attention. The remaining contaminants are not so common in the dairy industry, although should not be ruled out completely. Periodic testing is recommended to identify all possible contaminants. and determine gas conditioning requirements.

To minimise upset or malfunction of downstream processes, a wide range of technologies are available for biogas conditioning, which are discussed below.

6.4 H_2S Removal Technologies

6.4.1 Dry Scrubbing

A widely employed treatment for H_2S is the use of iron oxide coated support media or ‘iron sponge’. The H_2S in the biogas flows through a packed vessel containing the media and is absorbed onto the ‘iron sponge’ to form iron sulphide, with clean up efficiencies up to 99.98%.

The spent adsorption beds can be reactivated by air injection which converts the iron sulphide formed back to iron oxide and elemental sulphur.

Dry scrubbing method has the potential to clean up H_2S within the inlet supply gas down to levels of between 25 and 200 mg/L for gas supply at high H_2S concentrations (> 2000 mg/L).

This method is commonly employed for systems of capacity ranging from 100 m^3/hr to 2,500 m^3/hr.

6.4.2 Wet Scrubbing

Wet scrubbing is a process where biogas is introduced at the bottom of a packed tower while a water source is distributed in a counter-current arrangement to the biogas. Hydrogen sulphide dissolves in water as it is continuously recirculated through the tower, however it often requires large volumes of recirculated water to increase gas removal. Aerobically treated wastewater if available can be used as water source and returned to the same water source. In the presence of oxygen, hydrogen sulphite will oxide to sulphate. Often caustic soda is added to the water stream to improve removal of the H_2S (chemical scrubbing).

Under no circumstances should the waste by-product be returned to the anaerobic pond (since sulphides are likely to be regenerated).

Wet scrubbers are commonly employed for biogas volumes up to 11,000 m^3/hr and gas concentration up to 500 mg/L.

6.4.3 Biological Trickling Filter / biological scrubbing

The biological trickling filter configuration is very similar to the wet scrubbing, where biogas is introduced at the bottom of a packed tower. A water solution is distributed in a counter-current arrangement to the biogas and continuously circulated through the tower. The main point of difference is that this process relies on biological conversion of H_2S to elemental sulphur (rather than solubilisation) and addition of nutrients to aid the microorganisms which grow on the inert media of the packing.

These systems are capable of treating H_2S concentrations ranging from 1,000 - 5,000 ppm down to 50 ppm.

Combined systems of chemical wet scrubbing and biological scrubbing may be used for high concentration of H_2S (2,000 – 35,000 ppm).,

6.5 Moisture Removal Technologies

6.5.1 Condensate and Sediment Trap/Knock-out Pot

It is important that the knock-out pot is situated at the lowest point to enable collection of condensate water. It may be necessary to allow for several knock-out pots at different locations to drain condensate in its entirety.

Materials of construction of knock-out pots are generally stainless steel as a minimum to avoid corrosion impacts.

6.5.2 U-trap, Condensate Collection Sump

A U-trap is pipe shaped as a “U” in the condensate pipe to allow collection and drainage at the low point. Alternatively, several condensate pipes can be connected to a collection sump for disposal.

Key design considerations for U-trap is to ensure no biogas can escape when draining condensate (design for maximum pressure in biogas).

6.5.3 Refrigeration

The above techniques only remove water which condenses due to natural cooling of the biogas (as the ambient temperature is less than the biogas temperature from the digester). To achieve a significantly lower relative humidity, gas cooling/refrigeration can be adopted. A biogas dryer consists of a biogas/refrigerant heat exchanger (to cool the biogas) and a refrigeration system (to continuously provide cooling). In conventional systems, the biogas is cooled from approximately 30°C to approximately 5-10°C (i.e. below the dew point). Water then condenses on the cooling coils of the refrigeration units and is collected in the condensate removal system. Cooling from 30 to 10°C removes approximately 75% of the biogas moisture. When the biogas then re-heats (either naturally, in a blower, or using a heat exchanger) the relative humidity is reduced).

To meet natural gas moisture requirements, refrigeration to ~0°C will be required. This will require the use of glycol or similar refrigerants.

Although relatively complex, this option could be considered if required by the industry as dairy companies are familiar with refrigeration systems.

6.6 Summary of Contaminant Removal Technologies for Biogas

Table 16 Comparison of H_2S Removal Technologies

Component	Dry Scrubbing	Wet Scrubbing	Biological Trickling Filter
✗ - No / Disadvantage, ✓ - Yes / Advantage / Ability to achieve, ✓✓ - Yes / Advantage / High ability to achieve /			
Process			
H_2S inlet concentration range	2,000 ppm	< 500 ppm	1,000 – 15,000 ppm
H_2S gas removal efficiency	✓✓ (98 -99%)	✓ (50 -90%)	✓✓
Volume of recirculation	NA	High	Medium
Media generation required?	✓	✗	✗
Dosing required	Air for regeneration	NA, sometimes caustic to increase removal efficiency	Nutrient and small quantity of air (oxygen)
Well established, widely used in for H_2S removal (Australia)	✓	✓	✓
Operation / Maintenance			
Simple to operate / requires less operator attention	✓✓	✓✓	✓
Easy to dispose waste-by product appropriate disposal	✗ [1]	✓	✓
Cost			
Capital cost	Low	Medium	Medium - High
Operating cost	High (Considers media regeneration, media replacement and media disposal)	Medium (Considers pumping from water recirculation) High if caustic used	Low (Considers nutrient and oxygen, recirculation pump)
Footprint requirement	Low 25 – 100 m^2	Low 50 – 200 m^2	Medium 100 – 300 m^2

Table 17 Comparison of Moisture Removal Systems

Component	Condensate and Sediment Trap/ Knock-out Pot	U-trap, Condensate Collection Sump	Refrigeration
× - Disadvantage / unable to achieve, ✓ - Advantage / ability to achieve, ✓✓ - Advantage / high ability to achieve			
Process			
Moisture removal	Free water removal only	Free water removal only	✓✓
Operation / Maintenance			
Well established, widely used in for moisture removal (Australia)	✓	✓	✓
Simple to operate / requires less operator attention	✓✓	✓✓	✓
Cost			
Capital cost	Low	Low	Low
Operating cost	Low	Low	Low
Footprint requirement	Low $< 1\ m^2$	Low $< 1\ m^2$	Medium $< 30\ m^2$

6.7 Summary of Design Criteria

While the biogas conditioning requirements are largely determined by the downstream biogas conversion technology, one important criteria to note is material selection. As a minimum, stainless steel should be specified to minimise corrosion. Brass and copper are not corrosion resistant and not deemed appropriate.

As a summary, H_2S removal is not required for some gas micro-turbines however moisture removal is generally required. More complex conversion technologies generally demand lower relative humidity. The tables below identify the requirements for contaminant removal dependent on the use of the biogas.

Table 18 Biogas Converters Conditioning Requirements

Biogas Conversion	Hydrogen Sulphide Removal Requirements	Moisture Removal Requirements
Flare	No (unless there is a SO_2 limit on gaseous emissions)	Yes – Free water removal (e.g. Knock-out pot/U-trap)
Boiler	Depends on H_2S concentration and type of boiler < 1,000 ppm	Yes – Free water removal (e.g. Knock-out pot/U-trap)
Micro-turbine	Depends on H_2S concentration and type of gas turbine <1,000 ppm	Yes – Drying (e.g. refrigeration)
Cogeneration	Yes	Yes – Drying (e.g. refrigeration)

Table 19 Key Concerns and Mitigation Strategies for Biogas Contaminants

Component	Impacts	Mitigation Strategy
Hydrogen sulphide (H_2S)	Corrosive to pipework, odorous emission	Scrubber to reduce corrosive gas

Component	Impacts	Mitigation Strategy
Water vapour / moisture	Pipe blockage, prevents capture of biogas	Condensate or sediment trap/knock-out pot
Carbon dioxide (CO_2)	Corrosive to pipework, lowers ability to maximise energy production.	Nil required for most engines / applications
Nitrogen (N_2)	Nitrous oxygen at high temperature, lowers ability to maximise energy production.	Nil required for most engines / applications
Oxygen (O_2)	Risk of explosion	System designed to eliminate air ingress
Siloxanes	Leaves deposit, causes abrasion	Filtration
Dust	Frequent operational maintenance	There are limited technologies available to remove dust (bag filter)

6.8 Cost Estimates

The indicative cost estimates presented in Table 20 below assume that the inlet H_2S gas concentration is a maximum of 1,500 ppm. Gas cleaning is only applicable for IC engines and co-generation systems as H_2S is not usually a significant concern for flare and boiler.

Table 20 H_2S Removal Technologies Cost Estimate

Parameter	Unit	Small Plant	Low-Medium Plant	High-Medium Plant	Large Plant
Nominal wastewater flow	m^3/d	500	1,500	4,000	7,000
Biogas flow	m^3/d	500	1,500	4,200	7,300
Dry Scrubber					
CAPEX	$	20,000	50,000	140,000	230,000
OPEX	$/year	10,000	30,000	70,000	110,000
Wet Scrubber					
CAPEX	$	30,000	80,000	200,000	340,000
OPEX	$/year	10,000	10,000	20,000	30,000
Biological Trickling Filter					
CAPEX	$	30,000	90,000	230,000	400,000
OPEX	$/year	10,000	10,000	10,000	10,000

The table above indicates that the capital cost for biological scrubbing systems are highest compared to dry and wet scrubber systems. A wet scrubber system is higher than that of a dry scrubber, mainly due to the large recirculation flows (therefore pumps required).

However, operating costs for dry scrubbing systems are the highest due to cost associated with media regeneration and disposal requirements.

Table 21 Biogas Conditioning Cost per Biogas Production

Component	Capital Cost	Operating Cost
Dry scrubber	\$500 to \$1,000 per m^3/hr of gas	\$10 to \$15 per m^3 of treated gas.
Wet scrubber	\$500 to 1,500 per m^3/hr of gas	\$3 to \$15 per m^3 of treated gas
Biological trickling filter	\$1000 to 1,500 per m^3/hr of gas	\$3 to \$10 per m^3 of treated gas
Knock-out pot/ Sedimentation trap	Minimal	No foreseen operating cost however regular maintenance is required
U trap	Minimal	No foreseen operating cost however regular maintenance is required

7. Biogas Conversion and Usage Review

7.1 Overview

This section outlines biogas conversion technologies and conditioning requirements, and associated capital and operational costs and common pitfalls to be wary of.

As noted in Section 6, biogas represents an opportunity to make use of the available calorific value (energy). In many municipal and industrial applications, it is fair to say that the collected biogas is simply burnt (flared) as a means of disposal and minimisation of greenhouse gas nuisance. This practice has largely stemmed from historical practices and the previous high cost of installing energy conversion equipment.

7.2 Electricity Market

The Renewable Energy Target is a government initiative to encourage generation of electricity through renewable sources. The target aims to source 2% of Australia's electricity sustainably and have since increased the target to 20% by year 2020, in other terms, capturing 33,000 GW of reusable energy.

The target rewards carbon credit in two categories, small-scale renewable energy scheme (STCs) and large-scale renewable energy target (LGCs), with the latter applicable to most dairy manufacturing and anaerobic digestion plants. In the LGCs category, one 1 MWh of electricity generated is equivalent to one Renewable Energy Credit (REC). For example, a 1 MW plant operating at full capacity for a day receives 24 RECs.

The REC value is relatively volatile due to the supply and demand wholesale market. As recently as two years ago, the LGCs spot price hovered under $30, however quickly increased to $80 (Jan 2016) due to a range of market factors. It has become evident that the current LGC unit price is trending upwards, providing some significant incentives to industries already considering capturing and converting biogas. If not already, this would highlight how trading REC values could potentially change the industry's approach to electricity production.

Figure 11 Large scale Generation Certificate Spot Price

7.3 Technology Description

7.3.1 Gas Flaring

A flare system involves a tower column where biogas is burnt off to reduce methane emissions. A range of flare types are used including open and enclosed flares. A schematic of flare types is shown below.

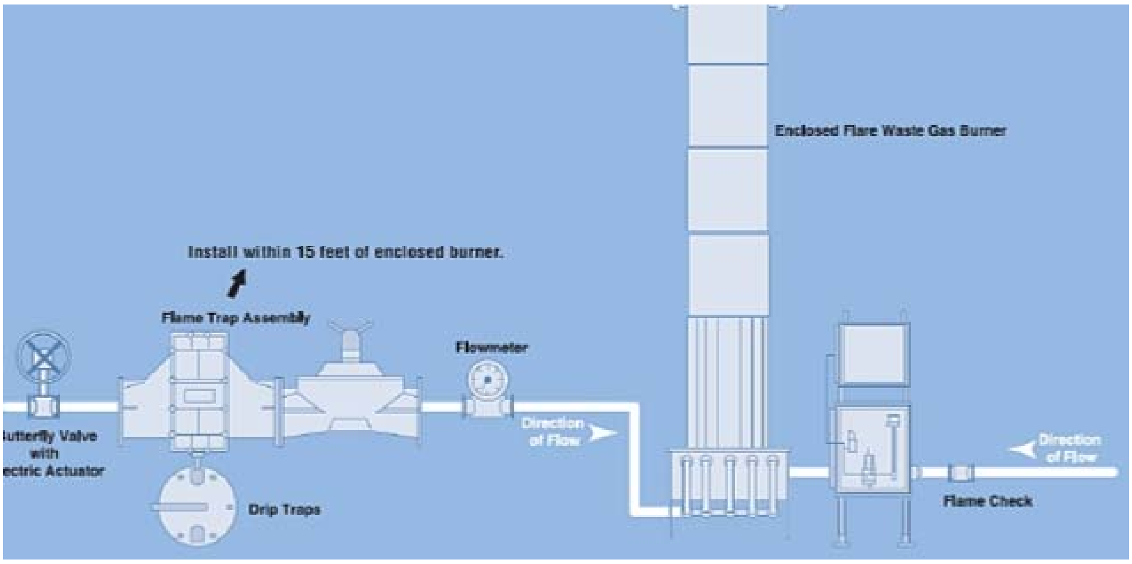

Figure 12 Gas Flaring

In general, closed flares combust at a higher temperature than open flares. The destruction efficiency of a flare is dependent on the temperature of combustion and time that the exhaust gases are maintained at this temperature. Closed flares typically combust at approximately 1,000°C and attain a destruction efficiency of 98-99.9% whereas open flares burn with a low intensity and the ambient temperature quickly cools the exhaust gases. Typical destruction efficiencies are 90-95%.

A flare requires all free water from the biogas to be removed using a well-designed condensate removal system. Specific design and control requirements may vary between states in Australia.

7.3.2 Boiler

Biogas can also be used as a boiler fuel, directly or co-fired with existing gas feed to provide hot water for site use. Another option is to draw sludge from the lagoon, use boiler fuel to heat sludge and return it to the lagoon to maintain or increase temperature of the lagoon system.

The outcome of an increase lagoon temperature is favourable, that is generation of higher biogas flow and reduction in sludge. However, adequacy of downstream biogas pipework and conditioning units must be checked to allow for increase of potential flows.

One common concern is corrosion in boilers due to hydrogen sulphide and moisture. Although control of corrosion is possible by specifying robust material selection.

Boiler suppliers do not typically stipulate strict concentration limits for hydrogen sulphide. It is up to the boiler owner and operator to assess the risk due to hydrogen sulphide in the biogas and decide whether hydrogen sulphide removal is necessary. In general, boilers using biogas with a hydrogen sulphide concentration of <1500-2,000 ppm, do not require hydrogen sulphide removal before use (based on supplier specifications).

7.3.3 Internal Combustion (IC) Engines

Biogas fuel for IC engines may be used to generate electricity, and is a long established and extremely reliable technology. The engines for biogas applications are generally 25-30% efficiency in converting fuel into electrical energy. The IC engines are modular in nature and provides flexibility for incremental expansion.

IC engines usually require attention from trained personnel to ensure continued efficient operation and they have relatively high maintenance costs due to more frequent regular maintenance.

Newer gas engines have higher conversion to electricity up to 40%, but do require stricter gas quality with H_2S < 150ppm.

7.3.4 Cogeneration (IC Engine Generator with Waste Heat Recovery)

Cogeneration (and often termed combined heat and power (CHP)) is similar to IC engines with the added ability to produce useful heat from the engine cooling system and the engine exhaust heat recovery system. IC engine generators, as stated, operate around 25-30% efficiency in converting fuel into electrical energy, but cogeneration can convert about 40% of the fuel energy to heat, meaning the overall efficiency is around 60 to 70%.

The significant increase in overall efficiency as a result of recovery and reuse of the waste heat from the engines reduces the volume of biogas that would be required for other heating processes.

The drawback is the cogeneration has relatively higher initial capital cost and operation and maintenance (O&M) costs than the engines without heat recovery. In many cases, it may be offset by higher energy conversion efficiency.

7.3.5 Micro-Turbines

Microturbines are a new type of combustion turbine being used for stationary energy generation applications. They are small combustion turbines, approximately the size of a refrigerator and can be located on sites with space limitations for power production.

Microturbines comprise a compressor, combustor, turbine, alternator, recuperator, and generator. Conversion to electricity is typically only 25%. Waste heat recovery can be used in cogeneration to achieve energy efficiency levels greater than 80%. These small power plants generally operate on low-CV fuels such as landfill gas and biogas. However, long term reliability and operating costs of micro-turbines have yet to be confirmed. Also microturbines are sensitive to siloxane contamination, and biogas supplied to microturbines is generally expected to require more gas conditioning than IC engines. As a general rule risk of high siloxane concentrations in the dairy industry is considered low.

7.4 Summary of Comparison of Biogas Usage / Applications

Table 22 Comparison of Biogas Conversion Systems

Parameter	Unit	Flare	Direct Combustion / Boiler	IC Engine Driven Generators	Cogeneration (IC engine with waste heat recovery)	Micro-turbine
Process						
Ability to generate electricity		✗	✗	✓	✓	✓
Ability to generate heat		✗	✓	✗	✓	✓
Efficiency	%	Closed loop 98-99.9% Open loop 90-95%	75 – 85%	25 – 30% (electrical) 35-40% (electrical – new gas engines)	28 – 30% (electrical) 30 – 50% (thermal) 35 - 40% (electrical – new gas engines)	28 – 30% (electrical) 40 – 60% (thermal)
Preferred capacity	kWe	Depends on gas yield	Depends on gas yield	5 – 7,000	5 – 7,000	25 - 500
Well established and widely used	✓	✓✓	✓✓	✓	✓	✓
Low noise pollution	✓	✓	✗	✗	✓	✓
Biogas Conditioning Requirements						
Biogas CH_4 conc	%	>50	>50	>50	>60	>55
Max allowable biogas H_2S concentration	mg/L	<1,000	<1,000	<250 <150 (new gas engines)	<250 <150 (new gas engines)	<1,000
Max allowable moisture range	%RH	Free water removal	Free water removal	<25 - 50	<50 - 80	<55
Max allowable siloxanes	mg/L			<2	<2	<0.0005

Parameter	Unit	Flare	Direct Combustion / Boiler	IC Engine Driven Generators	Cogeneration (IC engine with waste heat recovery)	Micro-turbine
Operation / Maintenance						
Simple to operate / requires less operator attention		✓✓	✓✓	✓	✓	✗
Quick start up		✓✓	✓✓	✓	✓	✗
Cost						
Capital cost		Low	Low	Medium	High	High
Operating cost		Low	Low	High	High	Medium
Others						
Footprint	m^2/kWe	Low 0.01	Low 0.01	Medium 0.017	Medium 0.023	Medium 0.026
Notes			Consistent biogas generation required to continuously feed boiler	Modular and easy to expand with increasing capacity		

7.5 Summary of Design Criteria

The biogas conditioning requirements are largely dependent on the conversion technology and manufacturer's warranty stipulation. It is therefore recommended that the biogas composition is clearly understood in order to allow for design of biogas conditioning equipment. Without these bases, it would be impossible to successfully eradicate typical pitfalls and malfunctions, such as material corrosion or engine failure.

The impact of maintenance is often costlier and time consuming as opposed to a thorough investigation and engineering upfront.

It is also common to incorporate a flare along with generators for emergency flaring while preventing damage of asset (i.e. cover rupture).

7.6 Cost Estimates

Capital and operational costs for biogas conversion technology are dependent on a range of factors and are often difficult to predict. To enable a basis for comparison of the different technologies, several assumptions have been made. The assumptions include:

Table 23 Assumptions for Biogas Conversion Cost Estimate

Component	Unit	Flare / Boiler	IC Engines	Co-Generation	Micro-Turbines
Operating hours	hours	6,240 (24 hours, 5 days over 52 weeks)			
Average inflow COD	mg/L	3,000			
Biogas production	m^3/kg COD	0.35			
Electrical efficiency	%	-	28%	29%	29%
Thermal efficiency	%	80%	-	40%	40%
Contingency	%	20%	20%	20%	20%

Similarly, to the CAL cost estimate, the range of costs provided are categorised under four different plant capacities. The costs presented are indicative only and serve to provide a general overview of the total expenditure.

Table 24 Biogas Conversion Cost Estimates

Parameter	Unit	Small Plant	Low-Medium Plant	High-Medium Plant	Large Plant
Nominal wastewater flow	m^3/d	500	1,500	4,000	7,000
Biogas flow	m^3/d	500	1,500	4,200	7,300
Biogas input	GJ/day	3,200	9,400	26,300	45,600
Flare / Boiler					
Estimated thermal output	MWh/y	800	2,100	5,900	10,200
Average electrical output	MW-e	0.13	0.34	0.95	1.63
Installed size	MW	0.20	0.50	1.20	2.00
CAPEX	***$***	***7,000***	***17,000***	***48,000***	***82,000***
OPEX	***$/year***	***1,000***	***2,000***	***3,000***	***6,000***
IC Engines					
Estimated electricity output	MWh/y	300	800	2,100	3,600
Average electrical output	MW-e	0.05	0.13	0.34	0.58
Installed size	MW	0.10	0.20	0.50	0.70
CAPEX	***$***	***55,000***	***145,000***	***379,000***	***650,000***
OPEX	***$/year***	***5,000***	***12,000***	***32,000***	***54,000***
Co-Generation					

Parameter	Unit	Small Plant	Low-Medium Plant	High-Medium Plant	Large Plant
Estimated electricity output	MWh/y	300	800	2,200	3,700
Average electrical output	MW-e	0.05	0.13	0.35	0.59
Installed size	MW-e	0.10	0.20	0.50	0.80
Estimated thermal output	MWh/y	1,000	2,000	3,000	6,000
Average thermal output	MW-th	0.16	0.32	0.48	0.96
Installed size	MW-th	0.20	0.40	0.60	1.20
CAPEX	***$***	***77,000***	***206,000***	***565,000***	***949,000***
OPEX	***$/year***	***6,000***	***16,000***	***44,000***	***74,000***
Micro-Turbines					
Estimated electricity output	MWh/y	300	800	2,200	3,700
Average electrical output	MW-e	0.05	0.13	0.35	0.59
Installed size	MW-e	0.10	0.20	0.40	0.60
Estimated thermal output	MWh/y	400	1,100	3,000	5,100
Average thermal output	MW-th	0.06	0.18	0.48	0.82
Installed size	MW-th	0.10	0.30	0.60	1.00
CAPEX	***$***	***83,000***	***222,000***	***609,000***	***1,023,000***
OPEX	***$/year***	***3,000***	***8,000***	***22,000***	***37,000***

Based on the assessment above, it can be concluded that the capital and operating cost per kW facility as below:

Table 25 Biogas Conversion Cost per kW Facility

Component	Unit	Flare / Boiler	IC Engines	Co-Generation	Micro-Turbines
CAPEX	$/kW	50	1,125	1,600	1,725
OPEX	$/kWh	0.0005	0.015	0.02	0.01

8. Case Study: Goulburn Valley Water's Tatura WWTP (and CAL)

This section provides an overview of Goulburn Valley Water's Tatura wastewater treatment plant design and biogas generation, performance metrics of the plant, success factors and lessons learnt for the wider audience, but especially those considering introduction of a CAL.

8.1 Description of System

Tatura Milk Industries (TMI) is located in Goulburn Valley in northern Victoria and has been manufacturing dairy products since 1907. The facility produces a combined 80,000 annual tonnes of dairy products, including cream cheese, nutritional powders, lifestage powders, milk and milk products and milk powders.

The Tatura manufacturing plant typically produces a daily wastewater flow of 4 ML/d, with instantaneous flows ranging from zero to 300 kL/hr (peak). Pre-treatment of the waste includes screening (coarse solids), flow equalisation in storage tanks and neutralisation. There is no provision for FOG removal.

Neutralisation of pH waste is either performed by mixing high pH and low pH waste, thereby minimising use of chemicals. If required, sodium hydroxide and CO_2 are used for pH adjustment. As a final pre-treatment step, waste stream is cooled from 42°C to approximately 38°C. The warm waste water is discharged to sewer where it mixes with town sewage and is pumped to Goulburn Valley Water's Tatura wastewater treatment plant (WWTP), located about 4 km south of the township, for treatment, storage, irrigation reuse and wetland discharge.

The Tatura WWTP comprises an inlet works with screening, three covered anaerobic lagoons operating in parallel, aeration lagoons and maturation lagoons. Biogas is collected and can be flared but is preferentially used to generate electricity. The power plant is owned and operated by Diamond energy.

A brief wastewater management history follows. The anaerobic lagoons were initially aerobic lagoons which, under increased loading (from factories) and odour complaints, drove GVW to seek improvements to the process. A covered anaerobic lagoon was identified as the preferred solution, being a robust, relatively simple and a low cost option. Hence, covers were installed in 2002 to convert the ponds to an anaerobic system, and have since mitigated odour issues and improved overall plant efficiency.

Shortly after GVW investigated the feasibility of utilising the biogas for power generation. Following a two GVW went to market via a tender process to convert captured biogas.

By 2006, a cogeneration system was built and commissioned by Diamond Energy. Diamond Energy was contracted by GVW to install the facility on a leased parcel of land within the existing WWTP. In turn, Diamond Energy receives revenue from electricity generated. The other option available at that time was the offset option, where heat waste or electricity was to be sold back to GVW for use within the WWTP. This was not taken up and eventually the cogeneration unit was configured to only generate electricity for supply to offsite grid.

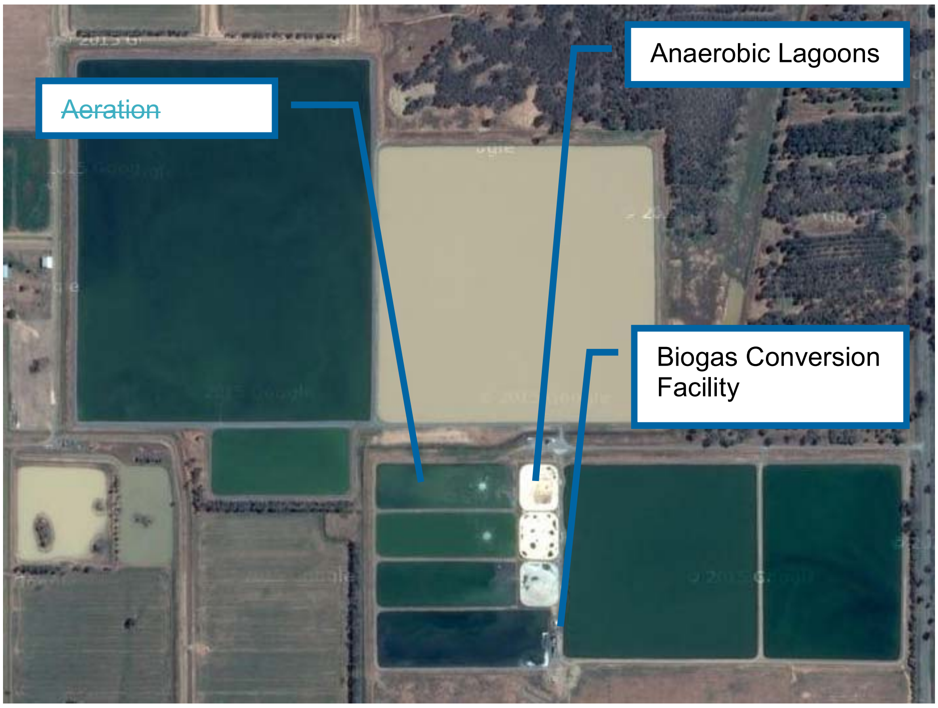

Figure 13 Aerial View of Anaerobic Systems

8.2 Design Criteria

8.2.1 Wastewater Characteristics

The wastewater characteristics discharging to the Goulburn Valley Water Wastewater Treatment Plant from 1 June 2015 to 30 April 2016 are presented below.

Table 26 Influent Wastewater Characteristics

Parameter	Unit	Average	Min	Max
Flow	kL/day	4,000	1,000	6,000
pH		6.7	6.4	7.2
Temperature	°C	26	19.4	31
TSS	mg/L	839	400	1,500
Alkalinity	mg/L	630	285	885
COD	mg/L	2,600	1,400	4,000
P	mg/L	22	5	45
N	mg/L	55	20	90

It is noted that the feed nutrient level is slightly low for good digestion. In some instances, nutrients may be low for good digestion and should be checked regularly to determine whether nutrient addition may be beneficial.

8.2.2 Covered Anaerobic Lagoon

The CAL receives a mix of domestic wastewater and industry waste (dairy processor, abattoir and food processor). The inflow to the lagoon ranges from 1 to 6 ML/d (peak flow of 542 kL/hr). Each lagoon volume is approximately 19 ML (70m length and 4m depth). Therefore, the HRT for anaerobic lagoon is less than 15 days.

Based on the wastewater characteristics, the average COD concentration is around 2,600 mg/L with removal rates averaging at 83%.

Figure 14 Covered Lagoons

8.2.3 Biogas Generator Systems

The cogeneration system has been selected to generate electricity with a capacity of 1 MW. As cogeneration requires gas conditioning, the following have been included in the process (in order from biogas collection pipework);

- Knock out pots
- Wet scrubber
- Coalescing filter
- Blower

Generator Systems

Biogas collection pipework (from above ground to underground to knock out pot)

Knock out pot

Wet scrubber with chemical dosing

L to R: Generator housed in container, scrubber and flare

8.3 Equipment Specifications

The generator selected for the Tatura WWTP is TCG 2020 (cogeneration system, modified to produce only electrical energy). The engine manufacturer is MJM.

8.3.1 Covered Anaerobic Lagoon

Further details of the CAL facility are summarised below.

Table 27 Tatura WWTP Anaerobic System

Components	Process Description
Pre-treatment	• Equalisation tank (725 kL) (no longer in use) • CO_2 and sodium hydroxide dosing facility for pH adjustment (no longer in use)
Inlet infrastructure	• Mechanical screening • Receives inlet through a flow splitter box which then distributes to 3 ponds (without flow control) • No grit removal
Pond configuration	• 3 x anaerobic lagoons operating in parallel • Each pond volume is approximately 19.6 ML (70m length and 4m depth)
Pond operation	• Temperature 25-30°C in summer and drops to 20°C in winter (no additional external heating)
Covers	• Floating PE covers • 1.4 mm thickness
Sludge desludging	• No allowance for sludge removal due to early CAL designs
Stormwater management	• Accumulated stormwater is pumped from the cover by manual stop/start of pump.
Effluent discharge	• CAL effluent transferred to adjacent aeration ponds prior to disposal community drain, irrigation and wetlands
Biogas accumulation	• Multiple passive venting systems for each pond • One draw off point from each lagoon • There is no equalisation of biogas due location of one pressure sensor (furthest away from co-gen) • Positive pressure biogas system (initially negative and then becoming positive)

8.3.2 Biogas Generator Systems

The cogeneration system is located adjacent to the anaerobic lagoons on the Tatura WWTP site. A summary of the key components of the biogas system is presented below.

Table 28 Tatura WWTP Biogas Conversion System

Components	Process Description
Biogas pre-conditioning	• Knock out pot at multiple points of the pond and a central knock out pot at the end of biogas collection pipework • Wet scrubber used with caustic for H_2S removal (from 2,000 ppm to <0.2 ppm) • Coalescing filter to further remove H_2S and moisture • Biogas CH_4 content above 65% post scrubber • Blower used to remove condensation within pipes prior to cogeneration (pressurised to wet bulb) • Siloxanes are not an issue.
Biogas conversion	• Flare is used when biogas generation exceeds demand and meets limits for flaring (CH_4: 60 – 80% (min 40%), H_2S: 4.3 - 4.6%, O_2: <5%, CO_2: 5 – 15 (<30%) • Cogeneration in use when cover pressure is between -15 kPa and 0 kPa and meets requirements • Cogeneration in place with capacity of 1.1 MW (oversized to cater for extreme events) • Electricity generated not used on site • An agreement is in place where an allocated parcel of land in the WWTP is leased to Diamond Energy (DE). DE generates and maintains the cogeneration unit and sells electricity to the grid • Electrical efficiency approximately 43%.
General	• Operates 24 h/d & 7 d/week however is dependent on biogas availability • Valve programmed to auto shuts at low biogas pressure • The generator and control system is housed in a 6.5 m containerised system • Webcam facility in place to visually inspect the plant remotely (height of covers, i.e. biogas build up etc.) • Stainless steel pipework throughout • Remotely monitored, and data accessed through SCADA, • Designed as an unmanned facility • Scheduled maintenance of generator/gas blower/alternator as per manufacturers' guidelines.

8.4 Capital Cost

The capital cost for installing covers over the lagoons was in the order of $5 million. The biogas collection pipework (excluding cogeneration unit) added costs of $500,000.

The operating cost for the lagoons and the capital cost for generation system were not disclosed.

8.5 Data and Performance Evaluation

The WWTP influent is sampled weekly for analysis while the biogas volume generated per day is recorded manually. Figure 15 and Figure 16 present data collected from 1 June 2015 to 30 April 2016 for analysis.

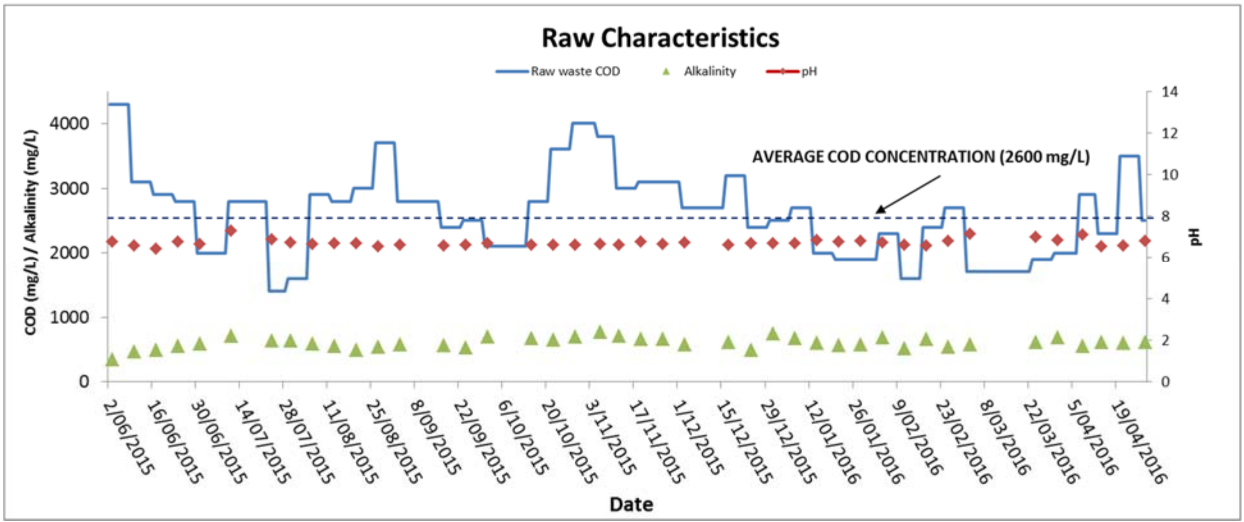

Figure 15 Waste Characteristics

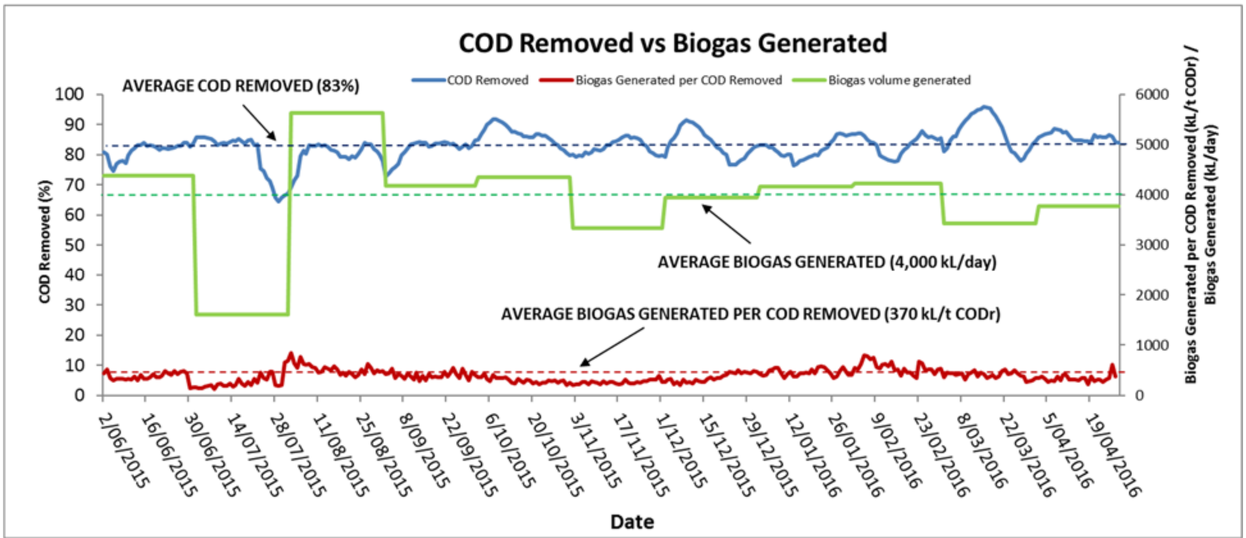

Figure 16 COD Removed and Biogas Generated

Figure 15 to Figure 16 demonstrate the variability of the COD concentration throughout the year, without obvious trends in summer and winter. As expected biogas generation responds directly with the fluctuation of the incoming COD concentration/load.

The period between 25 August to 15 December 2015 shows above average COD concentration, and the CAL's therefore have consistently produced biogas over the 4 months. As the COD concentration gradually decreases after December, biogas generation is reduced.

The data provided established that the average VFAs and alkalinity levels hover above the maximum concentrations which are not desirable. The pH of the waste stream is in the lower range which is again not desirable. All indicate a degree of operational instability of the CAL's.

However, gas is being produced which indicates that digestion is taking place. As a comparison, the biogas generation is estimated at 370 m^3/t CODr on average (which is marginally low as the theoretical value is predicted to be up to 500 m^3/t CODr) [1].

8.6 Equipment Maintenance

The Tatura plant has reportedly been operating smoothly and operator input has been minimal. A CCTV facility has been fitted for the main purpose of monitoring lagoon covers, hence taking the reliance off a full time operator.

Other major maintenance would be expected for covers (approximately every 15 - 20 years), gas pipework and flare systems.

Biogas collection systems are made from stainless steel to minimise corrosion. Even with careful selection of pipework and equipment material, presence of corrosion is evident in various sections of the plant (see knock out pot in figure, fencing, hand railings and valves).

[1] Average biogas flow has been calculated based on daily recorded data provided by GVW. This is based on the assumption that flow recorded corresponds to biogas flowrate (m^3/total blower run time) instead of totalised flow m^3/day).

9. Business Case Evaluation

9.1 Overview

In determining the application and feasibility of covered anaerobic lagoons for any dairy process operator, there are a number of aspects to consider. Broad alternatives exist between the dairy owning / operating their own wastewater treatment system versus contracting out and transferring responsibility of treating the waste and generating power. In addition, there are a range of designs and associated systems which are available (arrangement, gas usage)

Each alternative presents advantages and disadvantages to the dairy processing operator, and will be dependent on site specific factors. Determination of requirements and the viability of implementing a CAL will relate to:

- Type of wastewater effluent
- Space availability
- Location and proximity to plant / residential area
- Presence of skilled operators or willingness to train
- Cost associated with infrastructure requirements
- Ability to utilise biogas for heating or electricity
- Energy costs and requirement for generation rather than flaring

Risks associated with CAL implementation will include safety aspects (dealing with gas), structural and cover failure of the CAL, development of procedures / troubleshooting in the event of failure of the process, electricity spot pricing.

9.2 Risks and Opportunities

9.2.1 General

Risks and opportunities associated with covered anaerobic lagoon were identified and assessed from three different stakeholder perspectives, i.e.:

- Water Corporation
- Dairy Company
- Energy Generator/Provider

The key findings risks and opportunities for the different stakeholders are discussed below.

Table 29 Risks and Opportunities from Different Stakeholder Perspectives

Owner	Risk	Opportunity
Water Authority (WA)	Industry ceases to operate in the region or due to production changes loads reduce and biogas production declines Authority incurs unexpected/unforeseen/unbudgeted costs associated with the transfer/treatment/disposal scheme	With wastewater treatment infrastructure in place, attract other industry to the region Generate power from biogas (opportunity realised at Tatura) Separate transport and co-digestion to boost gas production

Owner	Risk	Opportunity
	Odour generation and septicity concerns with handling high strength waste	
Dairy Company	Needs to comply with TWA discharge conditions and risks fines for non-compliance Exposure to annual trade waste charge increases	Outsource operational responsibility for specialist wastewater treatment and disposal to others Provides alternative funding and commercial arrangements, freeing up capital for dairy processing investment Transfers EPA regulatory requirements for treatment and disposal to WA
Energy Generator	Lack of control on biogas availability and composition Industry ceases to operate in the region or due to production changes loads reduce and biogas production declines Regulatory changes which affect ability to supply/sell electricity to the market or otherwise affect commercial model	Maximise profitability by preferentially operate the facility when electricity spot price on market is high
Dairy Owns and Operates Plant and Biogas System	Risk of project delays and high costs due to lengthy and costly approvals process Underestimate staff training requirements to run and operate the facility, resulting in additional cost Odour generation and septicity concerns with handling high strength waste Upset of process due to dumps or wastewater characteristics variability, and either expensive tankering or slow management of loading to fix the process	Biogas can be utilised onsite as boiler fuel for steam generation and or in cogeneration facility offsetting off-site natural gas and power requirements. Opportunity for government grants

Where sewers are available, discharging of wastewater into the authority sewer presents a risk to the operating authority. If a local sewer is not available, then the onus is on the dairy operator to ensure appropriate treatment and disposal of effluent (by irrigation or other avenues). In a number of cases, recognising that wastewater management is not the core business of the dairy, treatment and / or energy generation, might be contracted out. These aspects are inherent in determining the way forward for the dairy processor in terms of management of wastewater.

A check list is provided in Section 9.3 below, to guide the user in assessing the viability of implementing a CAL.

9.3 Check List to Review Viability for CAL

9.3.1 SCENARIO 1: No wastewater treatment or no anaerobic system in place

1. Review wastewater characterisation
2. Determine suitability for anaerobic system
3. Review operational resource availability and skill set
4. Review current wastewater issues – performance, odours,
5. Is COD > 2,500 mg/L, fats > 500 mg/L, odours and / or greenhouse gases an issue ? Yes → covered lagoon or other anaerobic system
6. Determine sizing of lagoon or other constructed digester format
7. Review space availability and location at the site
8. Estimate gas generation rates
9. Review potential for use of the gas
10. Determine arrangement for gas collection and use
11. Review equipment and potential use of gas – applications and costs
12. Review current gas usage / costs and electricity usage / cost
13. Calculate proportion of energy that might be generated and costs saved
14. Determine feasibility / affordability for gas / energy conversion equipment
15. Are there uses for waste heat (heating of feed inflow)? Yes → cogeneration
16. Develop design and cost estimates for allocation of budget
17. Review resource viability and consider contracting out of treatment and gas usage.

9.3.2 SCENARIO 2: Existing uncovered anaerobic lagoon

1. Review current issues – odours, performance of treatment system
2. Are odours and / or greenhouse gases an issue? Yes → covered lagoon
3. Can a cover be installed on existing lagoon cost effectively or does a new lagoon need to be constructed
4. Determine arrangement for gas collection
5. Assess quality and quantity of gas generation
6. Determine potential uses of gas
7. Review equipment and potential use of gas – applications and costs
8. Review current gas usage / costs and electricity usage / cost
9. Calculate proportion of energy that might be generated and costs saved
10. Determine feasibility / affordability for gas / energy conversion equipment
11. Are there uses for waste heat (heating of feed inflow) ? Yes → cogeneration
12. Develop design and costs estimates for allocation of budget
13. Review resource availability and consider contracting out energy supply

In both scenarios, there are means of determining the value from implementing anaerobic digestion and gas usage, including benefit cost analysis. However, the incentives for installation of both cover and gas use will be determined by the cost of power and the budget available for the project. Payback for such a scheme is also important, and this can be up to 6 – 8 years. This could be considered a good investment (particularly when taking into account future power cost increases

Government grants and incentives can play a major role in the financial model when considering waste to energy implementation and the availability of appropriate financial support needs to be explored as part of any feasibility assessment.

A flow chart is provided in Figure 17 below to prompt key questions that relate to the viability of implementing CAL.

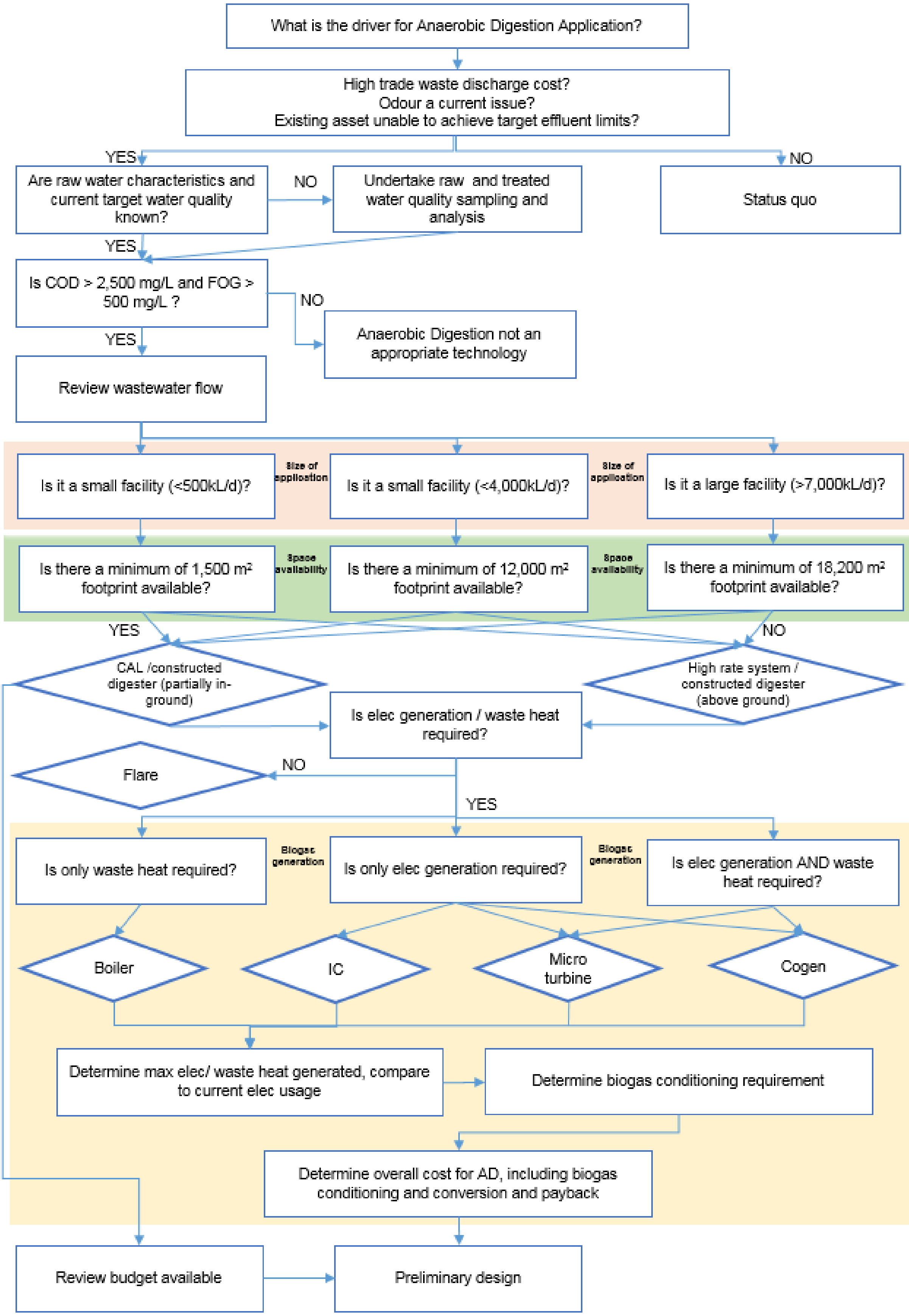

Figure 17 Flow Chart for Viability for Anaerobic Digestion

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Appendices

Appendix A – Dairy Wastewater Characteristics (Data collated by Dairy Australia)

Table 30 Characteristics of Untreated Wastewater from Dairy Plants

Product	pH	Biological Oxygen Demand (BOD) (g/m^3)	Sodium Adsorption Ratio (SAR)	Nitrogen (g/m^3)	Phosphorus (g/m^3)	Electrical Conductivity (uS/cm)
Whey [1]	4.6	35,000	3	1,400	640	N/A
Cheese/evaporated milk powder manufacturing, clean effluent stream [2]	N/A	12	N/A	N/A	N/A	880
Cheese/evaporated milk powder manufacturing, dirty effluent stream [2]	8-12	700 – 1,700	N/A	50-70	10	2,600
Cheese/milk powder manufacturing, effluent [3]	10.6	1,500	N/A	0.01	35	2,600
Cheese manufacture effluent [4]	6.9	2,800	21	150	42	3,500

Note 1 - [1]
Note 2– "This laboratory"
Note 3 – D. Kleinert (Murray Goulburn) pers. comm., December 2008
Note 4 – R. Knight (Murray Goulburn) pers. comm., January 2009

Appendix B – Installed Anaerobic Digestion Technology in Other Industries

Examples of anaerobic installations for other industries include:

- Covered anaerobic lagoon (medium rate) for poultry processing wastewater (Murarrie, QLD)
- Constructed conventional anaerobic digesters for piggery effluent (Berrybank VIC)
- Covered anaerobic lagoons for red meat processing wastewater (Teys / Cargill Wagga Wagga, NSW, Beenleigh, QLD, Nippon Meats, Oakey QLD)
- CAL AJ Bush Renderers
- CAL Biodiesel Australia rendering and biodiesel wastewater
- Covered anaerobic lagoons for vegetable wastewater at Shepparton and Tatura (VIC)
- Covered high rate anaerobic lagoon for municipal sewage treatment (Werribee, VIC)
- Covered anaerobic lagoon for biodiesel wastewater (Milawa, VIC)
- UASB system for brewery wastewater (Yatala, QLD& Hobart, TAS)
- IC at XXXX and Tooheys brewery (Brisbane and Sydney)
- IC at Smiths Snackfoods (Brisbane, QLD)
- UASB at Golden Circle cannery (Brisbane,QLD)
- UASB at Visy paper (Gibson Island, QLD)
- IC at Visy Paper (Smithfield, NSW)
- Hybractor at Gelita gelatine manufacturer (Bromelton, QLD)
- UASB at Cadbury Chocolates (Hobart, TAS)
- UASB at vegetable processor (Echuca, VIC)
- Biobed UASB at Mauri Yeast factory (Sydney, NSW)
- Proprietary UASB system for latex processing industry wastewater (Ipoh, Malaysia)

Appendix C – Trade Waste

Table 31 Example of Trade Waste Charges With and Without AD Treatment (Goulburn Valley Water)

Parameters	Units	Typical Raw Dairy Effluent	Typical Treated Dairy Effluent (Trade Waste Limit)	Unit Charges ($/kg or $/kL)	Goulburn Valley Water - Category 3 Trade Waste (No Treatment)	Percentage of Waste Charges (No Treatment)	Goulburn Valley Water - Category 3 Trade Waste (With Treatment)	Percentage of Waste Charges (No Treatment)
Flow	kL/d	1000	1000	$0.7778	$777.80	34%	$777.80	63%
BOD	mg/L	2500	500 (600)	$0.5182	$984.58	43%	$-	0%
Total N	mg/L	100	50 (150)	$0.7778	$-	0%	$-	0%
Total P	mg/L	50	20 (20)	$2.0747	$62.24	3%	$-	0%
Sodium	mg/L	500	500	$0.9188	$459.40	20%	$459.40	37%
Trade Waste Charge	ML/day				$2,284.02	100%	$1,237.20	100%
	ML/year				$833,667.67		$451,578.00	
Trade Waste Savings	$/year						$382,089.67	

Appendix D Current and Leading Practices in Dairy Wastewater Treatment

D.1 Current dairy wastewater treatment practices

The treatment of dairy processing wastewater will largely be governed by the water quality requirements stipulated by its end use, as outlined in the previous section

In general terms, current dairy processing wastewater treatment practices will include a combination of the following treatment steps, depending on the discharge route.

Primary treatment

- Equalisation tank
- Screening
- Fats, oils and grease removal

Secondary Treatment

- Organic load reduction (and removal of bulk of contaminants)
- Nitrogen reduction
- Phosphorus reduction

Tertiary Treatment

- Salt reduction
- Disinfection

Post Treatment

- SAR adjustment
- pH adjustment

Table 32 provides an overview of some of the wastewater treatment process units used in the dairy industry, along with key advantages and limitations.

Table 32 Typical Dairy Processing Treatment Processes

Process Units	Advantages	Disadvantages	Comments
Fats, Oils and Grease Removal			
Dissolved Air Flotation (DAF) / Induced Air Flotation (IAF)	Simple process and easy to operate Standard design packages available in the market Compact design	FOG management (storage and disposal) Chemical addition required for good removal Unreliable with variable loads Odour control	90 – 95% SS removal 70 - 85 % FOG removal
Organic Load Reduction			
Aerated Lagoon	Robust technology	Large surface area	Common technology

Process Units	Advantages	Disadvantages	Comments
(also refer inset)	High turndown ratio not a potential problem Simple operation	Requires periodic desludging High power costs	
Anaerobic treatment (ponds)	Resilient to system upsets / fluctuating influent quality Rapid start up after long periods without feed Option to capture and use biogas Generates less sludge than aerobic systems Low power requirements Low nutrient needs	Odour may be a problem – if ot properly designed and built	No energy input Simple operation (AL and CAL systems)
High rate anaerobic treatment	Resilient to system upsets / fluctuating influent quality Rapid start up after long periods without feed Easy to capture and use biogas Generates less sludge than aerobic systems Low power requirements Low nutrient needs	More capital intensive	
Activated Sludge Process (ASP)	Smaller footprint than aerated lagoon option Simple operation	Dairy wastewater gives poor settling sludge Prone to upset - Not good with variable loads Requires solid/liquid separation downstream of ASP (eg. clarifier) High power costs	Common technology
Sequencing Batch Reactor (SBR)	Low cost to install Separates liquid and solid phase, eliminating need for separate clarifier	Aeration is energy intensive Poor settleability causes problems More difficult to operate than continuous systems	Common technology

Process Units	Advantages	Disadvantages	Comments
Membrane Bioreactor (MBR)	Resilient to system upsets / fluctuating influent quality Not prone to settleability issues Standard design packages available in the market Compact design and small footprint High quality effluent Removal of bacteria and viruses possible	High capital investment High annual cost Requires extensive maintenance such as chemical cleaning and replacement of membranes Scaling of membranes from calcium occurs when used on dairy Membrane replacement approximately every 3 - 7 years	Not common in dairy industry
Trickling Filter (TF)	Moderate footprint No aeration required, however supplementary air (supply via blower) is required for high COD Low power consumption	Higher hydraulic profile Odour can be a problem	Robust process, but smells and flies can be an issue
P Removal			
Biological P removal	Well proven technology	Phosphorous bound in biological sludge will be released under anaerobic conditions	Incorporated into biological process
Chemical dosing (lime, alum , ferric)	Established process	Chemical sludge production, pH correction requirements Addition of salinity to effluent	
Salt Removal (For Irrigation Discharge Route)			
Filtration (Nanofiltration / Reverse Osmosis)	High quality effluent	Extensive pre-treatment required to prevent rapid membrane fouling Scaling an issue on dairy wastewater Energy intensive technology. (NF consumes less energy than RO and should be considered first).	Recovery dependent on wastewater quality, around 70% to 85%.

Process Units	Advantages	Disadvantages	Comments
		Disposal of brine as by-product of filtration (brine) needs to be in considered. Evaporation ponds are common.	
SAR Adjustment (For Irrigation Discharge Route)			
Calcium addition (e.g., Lime dosing, calcite filter, gypsum)			Aglime is applied directly to land as is common farming practice

In rural areas, lagoon treatment systems are very common, with cheap construction costs, low sludge yield and space availability. In addition, irrigation of treated effluent often does not require nutrient removal (rather relying on BOD, SS and FOG removal).

Comparison of lagoon design criteria are presented below.

Table 33 Typical Lagoon Parameters

Lagoon Type	Detention (day)	Area (ha per ML/d)	Typical Effluent BOD/SS (mg/L)	Sludge Yield (kg DS/kg BOD)	Energy Use (kWh/kg BOD)
Aerobic	250 – 500	25 – 50	20/30	0.2	0
Facultative	100 – 200	8 – 11	40/60	0.1	0
Anaerobic	15 – 50	0.4 – 2	100/100	0.2	0
Fully-mixed aerated	3 – 10	0.2 – 0.4	50/100	0.6	1 – 2
Partially-mixed aerated	5 – 25	0.3 – 1	50/50	0.3	1
Covered anaerobic	10 - 20	0.2 – 0.5	200/300	0.2	-6

D.2 Emerging Trends in Dairy Wastewater Treatment Practices

While typically treatment systems involve lagoons (assuming land is available), the need for pre-treatment or potential cost savings is driving some changes. Emerging trends in dairy and other industry waste water treatment include:

- Use of hydro-cyclones, fine sieving and screening as alternatives to IAF or DAF. The experience to date in the dairy industry, however, has been mixed.
- Increased interest in medium and high rate (small footprint) anaerobic treatment. Technologies range from the mature and well developed such as covered anaerobic lagoons (to collect gas), and constructed upflow anaerobic sludge blanket (UASB) systems to newer innovations including anaerobic flotation reactors (AFR) and anaerobic membrane bioreactors (AnMBR). AFR and AnMBR systems are well suited to wastewaters that contain elevated fats and oil concentrations, such as dairy manufacturing wastewaters.

- Advanced aerobic treatment methods such as mixed media bioreactors (MMBR) or granular activated sludge process are used and trialled. The granular activated technology (e.g. Nereda process) provides improved nutrient removal and sludge settling, resulting in a reduction in plant footprint.
- Desalination to enable reuse is widely practiced in other industries. A recent Australian example is the coal seam gas industry, which produces large amounts of saline water as a by-product of the gas extraction process. This water is typically desalinated and amended to enable reuse. To manage the brine large evaporation basins are often employed, however to reduce the size of these basins there is an increasing use of advanced brine management technologies. These vary from methods to assist natural evaporation to thermal desalination and /or crystallisation units. However, the applicability of the experience of the energy industry to the dairy industry is expected to be limited, as energy consumption is not a significant constraint for coal seam gas applications.
- Emerging technologies for lower energy brine management include forward osmosis and humidification / dehumidification. These technologies are currently being trialled at pilot phase with only a few full scale systems in place.

A summary of key wastewater treatment approaches, which could be considered current leading practice, applicable to dairy processing wastewater is presented below. The suitability of each approach will, of course, be dependent on a series of site specific / local factors and constraints, which will need to be considered, including:

- Influent flow variability and wastewater characteristics
- Effluent quality requirements
- Site/space constraints
- Power availability
- Technical constraints
- Operational constraints
- Capital/operating cost constraints
- Greenhouse gas / energy offsets
- Future cost of water and wastewater charges

A summary of leading practices and applications to the industry is contained in the table below.

Table 34 Summary of Leading Practice Technologies and Approaches

Technology/Approach	Status/Attributes	Summary
✘ - Disadvantage or cost / not recommended ✘✘ - Major disadvantage or cost / not recommended ✓ - Benefit / recommended, ✓✓ - Strong benefit / highly recommended, ? - Uncertain result or outcome		
Low Rate Anaerobic (pre-treatment)	**Organic and Nutrient Reduction** ✓ Mature and proven ✓ Energy recovery opportunities (can be difficult as ponds usually a long way from factory) ✓ Small amount of sludge for disposal (with correct management) ✘ Large footprint ✘ Need for skilled operations personnel	✓✓

Technology/Approach	Status/Attributes	Summary
Medium Rate Anaerobic (pre-treatment)	**Organic and Nutrient Reduction** ✓ Leading Practice ✓ Proven on a small number of facilities ✓ Energy recovery opportunities ✓ Small footprint ✓ Very small amount of sludge for disposal (with correct management) × Need for skilled operations personnel	✓✓
High Rate Anaerobic (pre-treatment)	**Organic and Nutrient Reduction** ✓ Leading Practice ✓? Proven (provided right variant selected) ✓ Energy recovery opportunities ✓ Small footprint ✓ Very small amount of sludge for disposal (with correct management) × Need for skilled operations personnel	✓
Floatation (pre-treatment)	**Solids and Organic Reduction** ✓ Mature and proven ✓ Small footprint × High chemical consumption × Increases wastewater salinity × Moderate amount of sludge for disposal × Odour potential	✓
Aerated Lagoons	**Organic and Nutrient Reduction** ✓ Mature and proven ✓ Low energy for aerobic treatment ×× Large area required × Some sludge requiring disposal (large amount periodically – i.e. every 10 years) × Odour	✓
Activated Sludge	**Organic and Nutrient Reduction** ✓ Mature and proven ✓ Good final water quality × Can have problems with poor settleability on milk wastewater ×× Moderate to high sludge production and high energy use ×× Need for skilled operations personnel	✓
Membranes – Filtration	**Solids Removal** ✓ Mature and proven ✓ Very good final water quality × Energy intensive × Chemicals required for CIP × Small amount of sludge requiring disposal	✓?
Membrane – Desalination	**Salt Removal** ✓ Mature and proven × Energy intensive ×× Brine and CIP waste requiring disposal/management	?
Cleaner Production	**Waste Reduction** ✓ Cost savings opportunities ✓ Reduced waste to manage COD, TSS, O&G, TDS	✓✓

Technology/Approach	Status/Attributes	Summary
Trade Waste	**Managed by Municipal Water Authority (or other 3rd Party)** ✓ Outsources disposal ✗ Pre-treatment usually required ✗ Probably extensive headworks charge ✗ Ongoing trade waste charges ✓ Transparent price setting (including increases)	✓✓

Of the above technologies, it is considered that anaerobic digestion offers a number of significant benefits to the dairy industry in terms of pre-treatment. While anaerobic digestion, by itself cannot reduce contaminants to required levels for irrigation or re-use, it is an excellent pre-treatment system, minimising BOD and thereby reducing trade waste charges (if discharged to sewer) or aeration costs associated with downstream aerobic treatment. At the same time, the reduction of organic material generates biogas, which can be used to generate energy for the site.

Anaerobic digestion is well suited to treat dairy wastewater being high in organic material and FOG.

Appendix E – Covered Anaerobic Lagoon Design Criteria

E.1 Key Operating Parameters

It should be re-iterated that maintaining an anaerobic system at optimum operating condition is essential. Refer Section 4.3 for these parameters.

E.2 Pre-Treatment

The need for the following pre-treatment steps (or consider implementing) should be assessed by each dairy manufacturing site as a minimum.

E.2.1 Screening

To remove large particles that will clog the downstream process, take up reactor volume or interfere with equipment.

E.2.2 Equalisation Tank

Equalisation tank is viewed as a pre-requisite to reduce flow variations and shock loads (especially pH and organic load) that can be detrimental to the health of the ponds and other treatment systems. In addition, a balancing tank provides constant flow to the CAL.

E.2.3 FOG Removal

One of the common problems for CAL operations is accumulation of scum from build up of FOG. High FOG content is typical for the dairy industry and many manufacturers implement IAF and DAF as a pre-treatment step. It should however be noted that some anaerobic systems will cater for high fat content and the need for this needs to be assessed dependent on characterisation of the wastewater. As a guide, maintaining the wastewater temperature within the CAL at say greater than 33°C (this will depend on the types of fats) will also prevent FOGs from separating from solution and causing excessive scum build up.

D.3 Pond Design

D.3.1 Loading Rate

The design of the pond (and determination of required volume) is a function of the organic loading rate and hydraulic retention time. These are respectively as follows [10]:

- 0.1 – 0.4 kg BOD/m^3.d (dependent on concentration)
- 20 – 40 days.

Recent modifications to lagoon to increase the loading rate (and reduce detention time), include:

- Provision of multiple inflow point to provide even feed distribution across the width of the pond (and minimise short circuiting);
- Sludge recirculation from end of pond to inlet (to increase the SRT and maximise contact between viable microbes and feed);
- Regular removal of sludge to prevent accumulation.

E.3.2 Depth

Pond depth for anaerobic systems is typically 4 – 7 m, with depths > 5.5 m preferred. Greater depth provides for sludge blanket formation and storage, promoting anaerobic reaction processes and rapid degradation of organics in the influent.

Water depth is measured from the bottom of the pond to the effluent outlet collection.

E.3.3 Geometry

Pond geometry are usually rectangular with length to width ratios of 2 - 3:1.

A geotechnical assessment is recommended to ascertain appropriate batter slopes based on site soil type. As a guide, sandy soil will need a minimum of 3:1 slope and clay soils 2:1.

E.4 Inflow Distribution

Discharge of waste stream is introduced at the bottom of the CAL pond and always below the sludge layer.

To improve distribution of waste, it is desirable to allow for multiple inlet pipes as opposed to one single inlet. Design should consider even discharge for all multiple inlets, so as to distribute solids evenly over the large pond area.

For discharge of waste stream from the top, inlet pipe should be located at the mid-point of the longitudinal centre line of the pond. Length of the pipe should be beyond the toe of pond embankment. Ideally each inlet pipe should be individually valved to allow flushing should they become blocked.

E.5 Effluent Collection

The design and construction of effluent collection needs to meet several criteria, including:

- Location well away from inflow distribution pipes to avoid short-circuiting
- Designed with a water seal to prevent gas escaping
- Allowance for maintenance access
- Allowance for a number of offtakes is ideal, including a surface overflow to allow removal of floating material.

E.6 Sludge

E.6.1 Sludge Collection

Sludge needs to be regularly removed from the treatment process to avoid excessive accumulation and reduction in retention time (sludge is formed from settling of influent solids, settling of inorganics (such as clay and dirt and the breakdown of the organic matter). Sludge gravitates to the bottom of the pond and so sludge removal should occur in this layer, typically every 2 – 3 years but should be more frequent. Desludging techniques are;

- Via a mechanical unit that moves along the pond floor and pumps sludge out. The difficulty in executing this method is not disturbing / removing the cover during this process; and
- Installation of a sludge pipe/s at the bottom of the pond to draw off sludge.

Mechanical unit desludging is often costly and can take many days to complete. This means that pipe draw offs are the preferred alternative. When designing a sludge pipe system, the following considerations must be incorporated:

- Multiple draw off points, for even sludge extraction;
- Positioned longitudinally down the center of the pond; and
- Where long pipes are incorporated, have pipe lengths the same or increase size of pipe network furthest away from pumping to improve extraction of sludge (and to minimise blockages).
- Ideally these should be able to be disconnected individually to allow clearing of blockages

E.6.2 Sludge Removal

Continuous and complete removal of sludge must be avoided. Doing so will reduce and disturb bacterial biomass and will take a lengthy period of time before the resultant system upset can recover.

The best practice is to intermittently draw off sludge and in small volumes (nominally weekly to monthly). It is noted that most plants only desludge annually or even less frequently, without impact on performance. It should however, be noted that this typically involves removal of the cover, which can be a significant task.

E.7 Covers

E.7.1 General

Materials of covers are discussed below but the main considerations for cover design is whether the cover is floating on the liquid surface or whether there is flexibility to enable some gas storage (resulting in inflating / ballooning of the cover). The advantages / disadvantages of each type relate to mitigation of the risk when the cover is in contact with surface scum / floating solid crust, which can result in blockage of the gas inlet pipe, versus, material flexibility, impact of wind and prevention of tearing due to storage under pressure.

Cover sealing to prevent gas release is also important as is gas collection. These aspects are discussed in the sections below.

E.7.2 Materials

In order to minimise operational disruption and unnecessary maintenance, integrity and therefore selection of pond covers is a key element in the design.

Selection of pond covers must take into consideration:

- Resistance to surface degradation and oxidation from UV radiation, increased temperature and moisture
- Ideally inert and compatible to wastewater characteristics; particularly sulphide, nitrate, ammonia, etc.
- Resistance to biological vectors (i.e. rodents and ants). Selection of appropriate wall thickness is necessary for pre-existing pest problems
- Minimal expansion / contraction due to temperature changes.

Two of the more common materials that are manufactured with these characteristics are;

- Polyethylene (PE), appropriate variance of PEs are High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE) and Low Linear Polyethylene (LLDPE)
- Composite / membranes (usually for larger operations).

Minimum material thickness of 2mm is desirable.

A comprehensive study [11] was undertaken to investigate properties of several cover materials and this is shown in Table 35below.

Table 35 Comparison of Cover Materials

Cover material	HDPE	LLDPE	fPP	R-EIA	CSPE
Material 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 & 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

E.7.2 Stormwater Collection

Stormwater collection needs to be integrated into the cover design to remove rain water.

Typically, covers are fitted with weighted pipes to create channels on the cover that eventually flows to a sump. Stormwater is pumped out from the sump through a permanent pump or a temporary mobile pump.

Multiple points are desired for changing wind direction which may concentrate rainfall on a particular area of the pond.

E.7.3 Installation and Sealing

The pond covers may be installed in two methods;

- Trenching, where pond liner and cover are used to line the trench and backfilled
- Concrete ring berm, where liner and cover are sealed and anchored bolted together on the concrete.

E.8 Biogas Collection

There are two methods to capture biogas:

- Negative pressure system, where a blower is used to extract biogas from under the cover (from around the perimeter or via a slotted gas collection pipe in one section)
- Positive pressure, where biogas is allowed to build up and by natural process flows from a point of high pressure to a point of low pressure.

Figure 18 Positive Pressure Covers for Anaerobic Lagoons (King Island Meat Processing CAL)

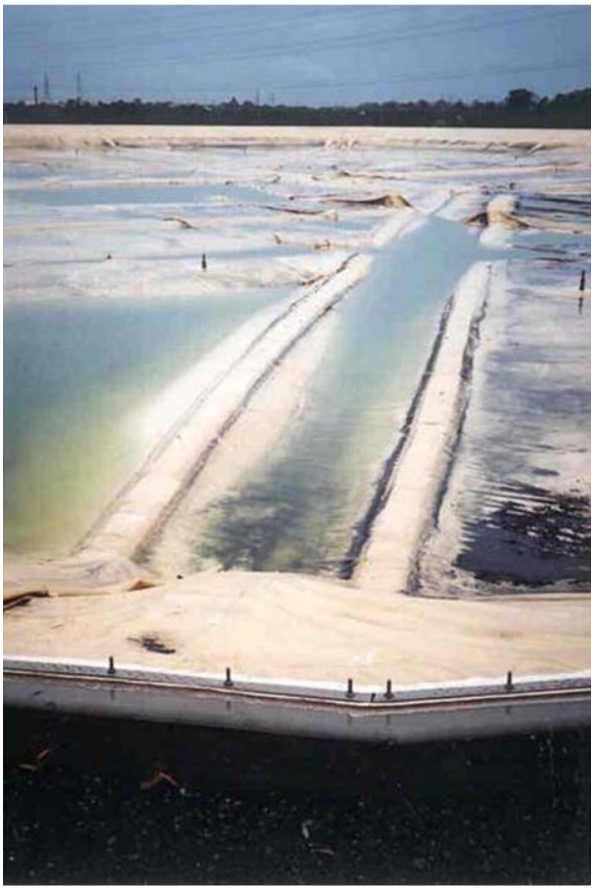

Figure 19 Negative Pressure Covers for Anaerobic Lagoons (Poultry Processing CAL)

Where a negative pressure system is implemented, caution must be taken to select a durable pond cover and any possibility of leaks (or weak points) are sealed off appropriately. Failure to do so will expose biogas to the atmosphere (when the blowers are turned off) or cause air ingress through the covers (when the blowers are turned on). This could end up in the explosive range of oxygen and methane or will impact the methanogenic bacteria that are obligate anaerobes and hence on methane conversion rate. To add to the complexity, it is a difficult task to locate the leak(s). The presence of hydrogen sulphide gas in the biogas presents a serious risk of exposure during testing and times of leakage.

Alternatively, when implementing a positive pressure system, caution must be taken to ensure excessive biogas accumulation is avoided. Expansion of covers beyond allowable limit may impact on integrity of the cover (a flexible cover is more appropriate).

Biogas extraction needs to be monitored and controlled through a PLC system to mitigate this potential problem.

As a general rule, each kg COD removed has the potential to generate around 0.5 m^3 of biogas (theoretically). Gas collection and associated infrastructure should use this value as a guide if actual production is unknown.

Safety and integrity of the cover needs to be incorporated into the design. Multiple and accessible pressure relief valves are also necessary as an overpressure safety control. For floating covers this may simply involve a series of pipes welded into the cover extending below the liquid surface.

E.9 Instrumentation

System control of CAL, especially biogas capture is best performed automatically by the PLC although some manual procedures may be possible.

As a minimum, CAL system would require on-line instrumentation for continuous monitoring and analysis, as follows.

- Biogas flow meter (instantaneous and totalised capability)
- Multiple pressure relief valves (at high points and accessible) or flare
- Biogas pressure meter (high accuracy and sensitivity) – in cover and downstream of extraction fan
- Biogas methane composition
- Oxygen concentration in gas line downstream of fan
- Sludge outlet flow meter
- Flow (outlet)
- Temperature (outlet)
- pH (outlet)

If upstream instrumentation is not in place (after equalisation tank) then these need to be added to the list:

- Effluent inflow
- pH (optional)

E.10 Operation and Maintenance

Design of the ponds should allow for the following,

- Scum breakup mechanism (such recirculation of sludge to corners)
- Sampling points - gas
- Inspection ports – check scum accumulation and blockages
- Sampling points – effluent collection

It should also be noted that vegetation around the inner walls / embankments of a pond will need regular control to protect cover integrity and minimise sanctuary of vectors.

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