# final report

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# Treatent of abbatoir wastewater using a covered anaerobic lagoon

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**SUMMARY**

The Australian meat processing industry is one of the largest amongst the rural industries in Australia and it is coming under increasing pressure from environmental authorities to reduce its environmental impact. In particular, improved wastewater treatment and reduction of associated odours is being called for. Traditionally, the moderate to high organic strength wastewater from abattoirs receives some form of pre-treatment (eg. Screens, DAF) followed by simple anaerobic and aerobic lagoon treatment.

Anaerobic lagoons are a key component of these treatment systems, being responsible for the removal of the bulk of the organic carbon. They are a simple and low cost technology but they accept only low organic loading rates (OLR = 0.5 $kgCOD.m^{-3}.d^{-1}$) and require long hydraulic retention times (HRT > 20 days). The main aim of developing covered anaerobic lagoon technology has been to improve the performance of anaerobic lagoons (ie. increase OLR and reduce HRT) while maintaining simplicity and low cost.

This project commenced with a literature survey of anaerobic lagoon technology. There was a substantial range of data demonstrating the typical performance and limits of uncovered anaerobic lagoons and the development of covered lagoons to improve performance. There was no specific application, however, of covered anaerobic technology to abattoir wastewaters.

A laboratory scale study followed, in which three covered anaerobic lagoon reactors were operated over a 50 week period with each demonstrating a contact, fixed film and mechanical mixing process respectively. The reactors incorporated an enhanced activity zone and a quiescent zone. Results supported the expectation that a partitioned lagoon could achieve higher OLR. In particular, the fixed film process showed potential to sustain very high organic loading (OLR = 2.2 to 3.7 $kgCOD.m^{-3}.d^{-1}$).

A 3000 $m^3$ covered anaerobic lagoon with baffle and sludge recycle, whose design was based on the data from the reactors, was constructed at Southern Meats, Goulburn. An identically sized, uncovered lagoon was also constructed to act as a control for the trials. The objective of the field trials was to demonstrate successful operation of the covered lagoon at 1.2 $kgCOD.m^{-3}.d^{-1}$ with a HRT of 5 days.

To date, the lagoons have been loaded to 0.5 to 0.6 $kgCOD.m^{-3}.d^{-1}$ (HRT 12 to 10 days) with COD removal greater than 80%. Poor design and construction of the wastewater distribution system to the lagoons has limited the OLR which can be applied. In addition, a bubble in the cover that is associated with the lifting of the baffle was detected towards the end of 1997. Investigations and modifications are currently being undertaken to overcome these problems and trials will continue in 1998 to demonstrate the covered lagoon's performance at a loading of 1.0 to 1.2 $kgCOD.m^{-3}.d^{-1}$.

As well as odour reduction, the collection and utilisation of anaerobically generated biogas presents a significant benefit from this technology. A preliminary economic assessment of biogas utilisation has been undertaken with this project and indicates the potential for significant savings and potential payback within two to three years.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| COD | Chemical Oxygen Demand |
| BOD | Biochemical Oxygen Demand |
| OLR | Organic Loading Rate |
| HRT | Hydraulic Retention Time |
| SS | Suspended Solids |
| VSS | Volatile Suspended Solids |
| TSS | Total Suspended Solids |
| VS | Volatile Solids |
| TS | Total Solids |
| MLVSS | Mixed Liquour Volatile Suspended Solids |
| TDS | Total Dissolved Solids |
| O&G | Oil and Grease |
| DAF | Dissolved Air Flotation |
| BNR | Biological Nutrient Removal |
| STP | Sewage Treatment Plant |
| BMP | Biochemical Methane Potential |
| UASB | Upflow Anaerobic Sludge Blanket |
| UAF | Upflow Anaerobic Filter |

# 1. BACKGROUND

The Australian meat industry is one of the largest amongst the rural industries in Australia earning approximately Aus$5.0 billion in 1996/97 (MRC 1997). The industry is tending towards centralisation and development of relatively large meat processing facilities where 43 of the total 148 processing plants in Australia earn approximately Aus$3.5 billion of the industry's total earnings from the export market (MRC 1997).

## 1.1 Wastewater Management in the Meat Processing Industry

The meat processing industry is coming under increasing pressure from environmental authorities to reduce its environmental impact (Pitt & Skerman, 1992) and, in particular, improve wastewater treatment and reduce associated odours. These facilities produce a moderate to high strength organic wastewater (Chemical Oxygen Demand (COD) 4,000 ~ 8,000 $mg.L^{-1}$). Traditionally, the wastewater from such facilities receives some form of pre-treatment (eg. screening and/or dissolved air flotation (DAF)) followed by lagoon treatment (eg. anaerobic, aerobic and stabilisation lagoons or ponds) and disposal to land, waterways, or sewer.

The low cost of lagoon technology makes it a favourable option in Australia where land availability is good, however simplicity limits its effectiveness as a suitable treatment technology. Lagoons can only be organically and hydraulically loaded at relatively low rates and are consequently easily overloaded. This reduces the level of treatment achieved, increases the environmental impact and puts pressure on abattoir management to augment treatment systems by building more lagoons and obtaining additional land over which effluent irrigation can be applied. Further, open lagoons, in particular anaerobic lagoons, are renowned for producing nuisance odours.

Anaerobic treatment removes the bulk of the organic content of the high strength wastewater, although a pre-treatment step, such as screening and/or dissolved air flotation (DAF), will also be responsible for a large removal of COD. The anaerobic treatment stage has received much attention by researchers in an effort to improve treatment. High rate anaerobic systems, such as Upflow Anaerobic Filter (UAF) and Upflow Anaerobic Sludge Blanket (UASB) have been investigated by many researchers for abattoir application (Johns 1993). These high rate systems, however, are high in capital cost and require relatively intensive operation and maintenance.

In an effort to maintain the low cost and simplicity of lagoon treatment technology, while improving treatment, reducing odours and offering the potential for biogas utilisation, the concept of covering anaerobic lagoons has been developed. Covered anaerobic lagoons have been successfully applied to a range of industry wastewaters demonstrating their cost effectiveness (Faruqi 1995; Zhu *et al.* 1997), although no application has been described in detail for abattoir wastewaters in Australia.

## 1.2 Literature Review

A preliminary literature review which provided a general overview of issues was reported by Faruqi (1995). This review identified industry size, wastewater composition, anaerobic wastewater treatment technology and the latest trends in abattoir wastewater management. The review is summarised in Section 1.2.1 while the full report is provided in Faruqi (1995).

A more detailed literature review of abattoir wastewater composition and anaerobic treatment technologies was subsequently undertaken by Zhu *et al.* (1997) preceding, and in conjunction with, the Laboratory Studies for this project. The emphasis of this later literature review was on developments of anaerobic lagoon technologies and abattoir wastewater treatment relevant to this project. This review is summarised in Section 1.2.2 while the full report is provided in Zhu *et al.* (1997).

In both literature reviews, many papers and publications *etc.* of relevance to the treatment of wastewater by covered anaerobic lagoon technology were found, nonetheless, no report specific to treating abattoir wastewater with covered anaerobic lagoons was found.

### 1.2.1 Preliminary Literature Review

The majority of the literature reviewed was post-1990, as earlier literature had been reviewed by Johns (1993). Most of the research on anaerobic wastewater treatment of abattoir wastewater has been performed on beef cattle or pig abattoirs with no information on wastewater from sheep abattoirs.

The key findings are summarise below;

- The Australian meat industry is one of the largest amongst the rural industries in Australia and in 1991/92 the industry earned approximately Aus$2.8 billion in exports alone.

- In 1993/94 about 8 million cattle and 32 million sheep and lambs were slaughtered in Australia, totalling of 2.5 million tonnes of carcass weight.

- In the past, abattoirs were designed to maximise meat production without giving much consideration to waste management issues. The major environmental issues faced by the red meat industry are disposal of large volumes of wastewater (200-2000 L per beast) high in organics (COD up to 8000 $mg.L^{-1}$), fats (up to 500 $mg.L^{-1}$) and nutrients (N:100-400 $mg.L^{-1}$, P:30-50 $mg.L^{-1}$) and increasing public pressure to reduce odours generated from lagoons holding the effluent. Currently, wastewaters from most abattoirs are treated in a series of lagoons (anaerobic and aerobic) sometimes with pre-treatment which might include sedimentation and/or dissolved air flotation.

- Anaerobic systems seem to be suited to the treatment of abattoir wastewater as they achieve a high degree of carbon removal, produce a smaller amount of sludge and are generally less expensive to construct and operate than aerobic systems (energy requirements can be up to $30W.m^{-3}$ for aerated systems, Green *et al.*, 1995).

During the last seven years, there has been an increase in research demonstrations of high rate anaerobic systems to treat abattoir wastewater. The UASB, Anaerobic Contact and UAF processes have been applied at full scale for treating abattoir effluent in Europe and the US. A hybrid anaerobic reactor (combination of an UASB reactor and an UAF) for abattoir wastewater treatment has been commissioned recently in Western Australia.

It is evident from this literature review that there have been some developments in improving anaerobic treatment technologies in the past few years. One of the most promising is the covered anaerobic lagoon. They are being installed all over the world because they achieve good carbon removal, prevent odour problems and allow for the harvesting and utilisation of biogas. Studies on intensifying anaerobic lagoons for improved performance have also been carried out in the last couple of years. Economic evaluations that covered anaerobic lagoons require smaller capital investments (US$ 50-70 per $m^2$ of covered surface) and maintenance and have short pay off periods (2-4 years if biogas is utilised) as compared to high capital investments (US $1000 per $m^3$ of digester) and management costs (up to US $20 per tonne of live weight) required for high rate anaerobic systems.

Covered anaerobic lagoons working as Bulk Volume Fermenters (BVF) offer a less expensive option than UASB's, yet may offer a similar level of treatment. Covered lagoons for the treatment of a range of wastewaters can be loaded up to 6 times the rate of uncovered lagoons reaching 0.36 $kgVS.m^{-3}.d^{-1}$ ( volatile solids) and 1 $kgCOD.m^{-3}.d^{-1}$. Biogas production rates of up to 1.38 $m^3.kgVSA^{-1}$ (volatile solids added) can be expected from covered lagoons. There is, however, just one report on a full scale covered anaerobic lagoon (Iowa, USA) treating abattoir (pork processing) wastewater and it only documents a limited amount of data.

### *1.2.2 Literature Review of Technology*

Abattoir wastewater is a medium-high strength organic wastewater, containing large amounts of fats, oil and grease. Normally these organic materials, which cause the majority of COD, can be degraded by bacteria in low rate and high rate anaerobic processes.

Enders *et al.* (1968) reported the following for their design and operation criteria for anaerobic lagoons treating beef slaughterhouse wastewater. An 87% Biochemical Oxygen Demand (BOD) removal rate was achieved with an OLR (organic loading rate) of 0.5 $kgBOD.m^{-3}.d^{-1}$ and a HRT (hydraulic retention time) of 5 days. The average wastewater temperature inside the lagoons was 22-27 $^{o}C$. Other research on low rate anaerobic lagoons has been reported by Stanley (1966) and Niles & Gordon (1970) who both described results using anaerobic lagoons to treat pig processing waste. In these cases the BOD removal rate reached 78-80% with an OLR of 0.29-0.32 $kgBOD.m^{-3}.d^{-1}$ and a HRT of 7-9.7 days.

High rate anaerobic processes have also been applied to treat abattoir wastewater. Satyanarayan *et al.* (1981) observed COD removals of 77-87% from a 15.5 litre pebble media column reactor that was operated on a slaughterhouse effluent at OLR between 0.8-4.0 $kgCOD.m^{-3}.d^{-1}$. Methane content of the biogas was between 70%-84%. Andersen and Achmid (1985) reported on a pilot scale upflow anaerobic filter with 1.5 m diameter and 4.9 m height, treating slaughterhouse wastewater. When normal pre-treatment was provided, principally for oil and grease removal, the removal of COD ranged between 72% and 92%. The reactor was operated at an OLR between 1.1 and 3.8 $kgCOD.m^{-3}.d^{-1}$. Sayed *et al.* (1987) operated two UASB reactors, both 33.5 litres in volume, for the treatment of slaughterhouse effluents. One reactor, maintained at 30°C and operated at OLR of 2.5-19.5 $kgCOD.m^{-3}.d^{-1}$, produced COD removals that ranged between 53-67%. The second reactor, maintained at 20 °C and operated at an organic loading of 3.0-12.0 $kgCOD.m^{-3}.d^{-1}$, produced COD removals between 40%-62%.

A pilot scale study was conducted by Harrison *et al.* (1991) to evaluate the treatment performance of an UAF on a slaughterhouse effluent. When organic loading was 0.47-2.98 $kgCOD.m^{-3}.d^{-1}$, hydraulic retention time 4.9-0.8 days and average influent temperature 23-27 °C, the COD removals ranged between 37% and 77%. The COD removals were related to the hydraulic retention time. The methane yields ranged between 0.19 and 0.23 $m^3 \cdot kgCOD^{-1}$ removed, and the average methane content of the biogas was 71%.

Anaerobic processes have been widely applied to treat agricultural wastes and food industry wastewater for many years. Though the biochemical reactions comprising various stages in the anaerobic degradation of organic materials have not been fully elucidated, better understanding of the complex interrelated mechanisms has engendered a greater confidence in the design and operation of large scale anaerobic treatment plants (Barnes & Fitzgerald, 1988).

According to their OLR's, anaerobic treatment processes can be classified into two ranges: high rate processes and low rate processes. The former includes UASB, UAF and anaerobic contact process, and the latter includes BVF and various types of in-ground anaerobic lagoons. The high and low rate processes both have their advantages and disadvantages. The high rate processes have higher efficiency and are more compact, but capital and operational costs are normally considerably higher than the low rate processes. The low rate processes, in general, have low capital and operational costs, especially when using natural lagoons, but low treatment efficiency and unpleasant odour emissions are their main weaknesses.

Many attempts to improve the treatment efficiency of a lagoon system have been made and a number of new ideas have been put into practice. A study was carried out on the intensification of a pond system by fibrous carriers packed in an anaerobic pond in China (Qi *et al.*, 1993). The performance of the pond system was remarkably improved with higher removal capacities and efficiencies for SS (suspended solids), BOD, COD, TN (total Nitrogen) and TP (total phosphorous). The mechanism for the intensified effects was ascribed to the increase of biomass in the form of biofilm attached to the surface of the fibrous carriers and more even distribution of the biomass in the pond. According to the statistical data, COD and BOD removal capacities of the intensified pond were 29% and 32% higher than those of the conventional pond respectively.

Research carried out by Polprasert and Agarwalla (1995) demonstrated the significance of biofilm (biomass growing on the side walls and bottom of the ponds) to substrate utilization. They thought that most research has dealt with only suspended biomass assuming that it is the major form of biomass responsible for substrate removal. However, the side walls and bottom of the pond can provide support for the growth of attached biomass (biofilm) which also aids in the degradation of organic carbon (substrate).

Saidam *et al.* (1995) reported on upgrading waste stabilisation pond effluent treatment by pilot-scale rock filters. The results showed that the filters can reduce the pond's effluent content of TSS (total suspended solids) and BOD by 60%, and TP by 46%, when the loading was 0.033-0.044 kgTSS.m$^{-3}$ and average temperature was 25 $^{o}$C.

Green *et al.* (1995) introduced a modified system called the advanced integrated wastewater ponding system. In this system, a fermentation pit and an adjustable submerged gas canopy formed an anaerobic zone (in-pond digester) to increase treatment efficiency and biogas recovery.

The concept to cover an anaerobic lagoon for the purpose of biogas recovery and odour control emerged in 1980's. Safely and Westerman (1989) released a report about a dairy cattle manure digestion in a covered anaerobic lagoon at low temperature (<20 $^{o}$C). Reduction in TS, VS, COD and VFA were 64%, 69% 70% and 88% respectively, with an OLR of 0.16 kgVS.m$^{-3}$.d$^{-1}$. The average methane yield was 0.39 m$^{3}$·kgVSA$^{-1}$ (volatile solid added).

Covering a lagoon gives increased temperature and performance, particularly in cool climates. This is important as Oldham and Nemeth (1986) reported a failure of anaerobic digestion using raw swine manure at 10$^{o}$C with a loading of 0.83 kgVSm$^{-3}$.d$^{-1}$ and a HRT of 25 days. However, satisfactory digestion was achieved at the above loading rate at temperatures above 18$^{o}$C. They concluded that anaerobic lagoons designed with a HRT of 60 days or more and an operating temperature of 15 $^{o}$C or higher would yield satisfactory performance. In addition, Oleszkiewicz and Koziarski (1986) reported that long term decomposition of swine manure in an anaerobic lagoon could occur at a loading of 0.20 kgCOD.m$^{-3}$.d$^{-1}$ and temperature of 22 $^{o}$C.

The recovery of methane using a submerged gas collector was demonstrated using a second generation AIWPS (Advanced Integrated Wastewater Pond Systems) prototype at the University of California, Berkeley (Green *et al.*, 1995). The optimization of in-pond methane fermentation, the growth of microalgae in a high rate pond and the harvest of microalgae by sedimentation and dissolved air flotation were studied. In the experimental system 17% of the influent organic carbon was recovered as methane and an average of 6 gC.m$^{-2}$.d$^{-1}$ was assimilated into harvestable algae biomass. A similar system is under evaluation at Flinders University, South Australia, for piggery effluent. (Fallonfield pers. comm.).

Covered anaerobic lagoons are also employed to treat food industry wastewater. Wajon *et al.* (1989) reported some preliminary results for a full scale BVF in Western Australia to treat fruit and vegetable processing wastewater (COD 3,400 mg.L$^{-1}$). The capacity of the fermenter was 12,300 m$^{3}$, with a depth of 5.5 m. The operation temperature was 16 - 25 $^{o}$C. At an average organic loading rate of 0.09 kgCOD.m$^{-3}$ the HRT was 54 days and the COD removal rate was 60%.

## 1.3 Laboratory Studies

### *1.3.1 Background*

The CRC for Waste Management and Pollution Control developed a 100 L laboratory scale prototype BVF reactor for treatment of intensive rural industry wastewaters (under CRC Project 5.1B). The experienced gained from operating this prototype formed the basis for the testing of three new laboratory scale covered anaerobic lagoon reactors for this MRC Project. The reactors allowed separate monitoring of the first, enhanced activity zone and the second, quiescent zone of a lagoon system. Furthermore, the physical separation allowed independent changes to the residence times in the two zones (analogous to moving the baffle in a full scale lagoon).

The laboratory reactors were used to test additional scenarios for direct comparisons under more controllable circumstances, whilst being fed actual abattoir wastewater. Data gathered from these reactors was used as the basis for field scale lagoon design and operation.

### 1.3.2 Summary of Laboratory Studies

The three laboratory reactors included Reactor 1 with mechanical mixer, Reactor 2 with fixed film media, and Reactor 3 with an anaerobic contact process.

Operation of Reactor 1, with mechanical mixer, was discontinued due to an excessive loss of biomass in the process. Hence, mechanical mixing is not recommended unless baffles could be arranged to ensure sludge retention.

Reactor 2, with fixed film media, achieved more than 90% COD removal at an OLR of 1.49 $kgCOD.m^{-3}.d^{-1}$. When the OLR varied in the range of 1.56-2.0 $kgCOD.m^{-3}.d^{-1}$, COD removals were 71-88%. Furthermore, when the OLR varied in the range of 2.2-3.73 $kgCOD.m^{-3}.d^{-1}$, COD removals were still 67-79%. During operation over this range of OLR the average gas yield was 0.219 $m^3$ $CH_4.kg$ $COD^{-1}$ removed and the apparent sludge yield was 0.077 $kgVSS.kgCOD^{-1}$ removed.

For Reactor 3, with the contact process, the average COD removal was also 90% when the OLR was 1.49 $kgCOD.m^{-3}.d^{-1}$. At OLR in the range of 1.30-1.71 $kgCOD.m^{-3}.d^{-1}$, COD removals were 58-82%. When the OLR reached 1.7-3.3 $kgCOD.m^{-3}.d^{-1}$, COD removals were 37-76%. During operation over this range of OLR the average gas yield was 0.157 $m^3$ $CH_4.kgCOD^{-1}$ removed and the apparent sludge yield was 0.094 $kgVSS.kgCOD^{-1}$ removed.

Most of the COD removal and gas production in the fixed film and contact process reactors (2 & 3) occurred in the enhanced activity zone. Reactor 2, with fixed film media, demonstrated preferred overall performance in terms of COD removal, gas production and operational stability. The results also demonstrated that maintenance of a high biomass concentration (>4500$mg.L^{-1}$) and activity is essential for the effective operation of an anaerobic lagoon with enhanced activity zone.

During start-up, the application of a cross-flow membrane was shown to be as effective as starting the reactor with colonised fixed film media. Sewage sludge seed alone, also works well if some 4000 $mg.L^{-1}$ can be applied.

Preliminary expectations where that an OLR of 1.0 $kgCOD.m^{-3}.d^{-1}$ was the likely nominal maximum loading possible for the contact process (Reactor 3). In the laboratory however, an OLR of 1.5 $kgCOD.m^{-3}.d^{-1}$ resulted in very stable operation and greater than 90% COD removal for both Reactors (2 & 3). Furthermore, stable operation of a fixed film system was demonstrated at an OLR of at least 2.0 $kgCOD.m^{-3}.d^{-1}$. In contrast, traditional anaerobic lagoons operate at 0.5-0.7 $kgCOD.m^{-3}.d^{-1}$ with only 70% COD removal. Hence, a design based on Reactor 3 (contact process), and as applied to the covered lagoon at Southern Meats, may expect a threefold increase in treatment efficiency.

Moreover, a construction cost analysis, with three designs, demonstrated the potential economic benefits from the application of these new lagoon technologies. The construction cost of a newly developed process is only 65-78% of the cost for a traditional lagoon, and only 15% of the cost for the BVF developed by ADI (Canada).

## 1.4 Continuing Laboratory Research

Work is being continued on the concept of a fixed film zone within a covered anaerobic lagoon. Previous experimental work showed this new technology to be promising in terms of degradation of organic material, hence bench scale lagoon reactors are being operated to optimise working parameters such as OLR, HRT, operating temperatures, volume ratios of high activity zone (fixed film) zone to settling zone. A model of the system is under development by an associated MRC Ph.D. student.

The fixed film laboratory reactor associated with this study has been operational for around eight months with a fixed film zone to settling zone volume ratio of 1: 4 compared to the 1:2 ratio of the previous MRC study. The high rate fixed film zone is operating at a temperature of around 35°C, whereas the low rate settling zone is at ambient temperature. Results to date show a COD removal of more than 90% even at an OLR of around 2.7 $kgCODm^{-3}d^{-1}$. The average gas yields have been around 0.20 $m^3 CH_4.kgCOD^{-1}$ removed and the percentage of methane in the biogas produced ranged from 75% to 80%. The TSS concentration of the reactor effluent is around 150 $mgL^{-1}$, representing about 95% TSS removal.

Experimental work will continue until May 1998 to complete this study and give enough data to prove the advantages of this intensified lagoon technology and provide a base for demonstration at a pilot scale.

## 1.5 Wastewater Management at Southern Meats, Goulburn, NSW

Southern Meats Pty. Ltd. represents a fairly typical export abattoir operating in Australia, handling approximately 4,300 or 7,500 head of sheep per day on a single or double shift respectively. The components of Southern Meats' wastewater treatment system, with basic performance parameters, are outlined in Table 1-1 and illustrated in Figure 1-1, while Table 1-2 provides some key data on water use at the plant.

The key factors of this system which impact on the operation of an anaerobic lagoon as a primary treatment stage are;

- Pre-treatment screens and DAF are not designed to remove significant levels of TSS and COD from the raw wastewater. The DAF removes Oil and Grease (O&G) only (~5,000 $mg.L^{-1}$ to < 1,000 $mg.L^{-1}$) for tallow recovery. The system is designed to achieve cooling to below 45 °C for O&G solidification;

- Flow rates vary depending on whether the abattoir is being operated on a single or double shift. Consequently, the primary treatment stage must have some degree of flexibility in hydraulic loading. Water use of 250 $L.sheep^{-1}$ is below average for the red meat industry (Faruqi 1995);

- The primary treatment stage must reduce significant amounts of COD and TSS, and further reduce O&G, prior to wastewater being delivered to the secondary treatment stage;

- Excessive COD and O&G load on the secondary treatment stage will reduce the effectiveness of this stage to achieve nitrification which is important for reduction of effluent ammonia; and

- Development and inclusion of biological nutrient removal (BNR) technologies, likely in the near future, will further increase the necessity for primary treatment to reduce the primary effluent COD and O&G.

Southern Meats are licensed by the NSW Environment Protection Authority (EPANSW) for environmental discharges. At present, limits are set on the BOD, TDS (total dissolved solids), Total N & Total P concentration levels in the effluent wastewater which is irrigated to pasture. Meeting these levels is not particularly onerous, although the EPANSW is advising Southern Meats that license levels will become more stringent. The EPANSW is ultimately planning to change to a load based licensing system where licensing fees will be based on the annual mass of BOD, TDS, Total N and Total P discharged.

Table 1-1. Southern Meats Wastewater Treatment System

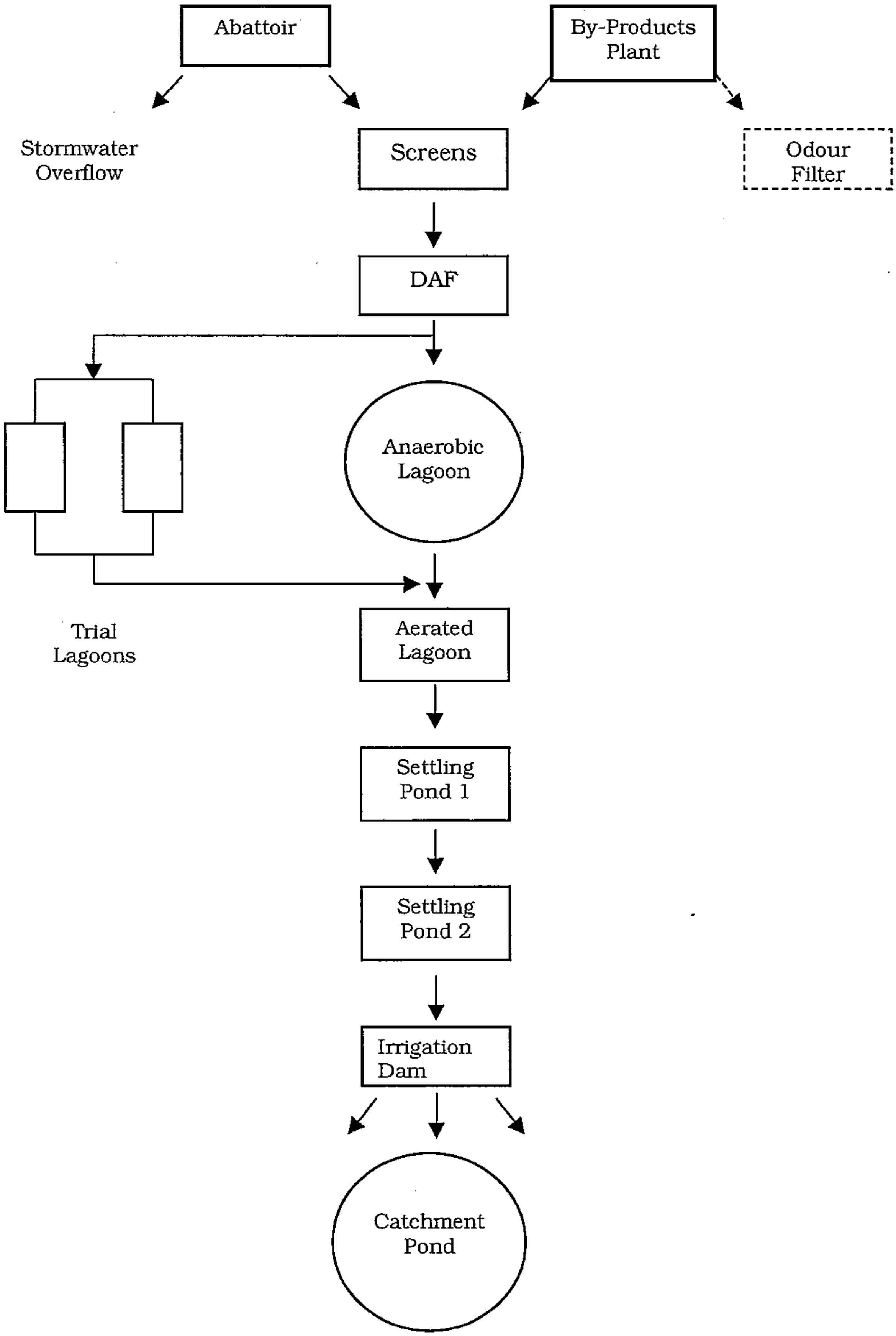
| Treatment Stage | Technology | Nominal Parameters of Effluent at Each Stage | | | | | |
|---|---|---|---|---|---|---|---|
| | | Flow ($ML.d^{-1}$) | COD ($mg.L^{-1}$) | O&G ($mg.L^{-1}$) | TSS ($mg.L^{-1}$) | Total N ($mg.L^{-1}$) | Total P ($mg.L^{-1}$) |
| Collection System | Gravity drainage | 1.0 to 1.6 | 3,000 – 15,000 | 5,000 | 2,500 | no data | no data |
| Pre-treatment | Screens and DAF (1) | | 3,000 – 15,000 | <1,000 | 2,500 | 300 | 35 |
| Primary Treatment | Anaerobic Lagoon | | <1,500 | <100 | <500 | 250 - 300 | 35 |
| Secondary Treatment | Aerobic & Stabilisation Lagoons | | <500 | <50 | <150 | 250 - 300 | 35 |
| Disposal | Pasture Irrigation | | - | - | - | - | - |

(1) DAF – dissolved air flotation

Table 1-2. Water Use at Southern Meats

| Parameter | Unit | Double Shift | Single Shift |
|---|---|---|---|
| Water Use | $ML.d^{-1}$ | 1.4 – 1.6 | 1.0 – 1.2 |
| No. of sheep | sheep | 7,500 | 4,300 |
| Water Usage Rate | $L.sheep^{-1}$ | 187 – 213 | 233 – 279 |

Figure 1-1 Southern Meats Wastewater System Schematic



# 2. PROJECT OBJECTIVES

The objectives as set out in the Contract were to be achieved by June 1996. Due to the delays and alterations experienced during the design and construction of the trial lagoons by a second MRC contract (M665.B), however, the June 1996 deadline was not met, although the objectives remained current. Further, the objectives were to be based on four main operating stages, however, due to the problems alluded to above, only operation at stage 1 was achieved by the delayed conclusion of this project in December 1997.

The four main operating stages formed the basis of the Project's methodology and are accordingly discussed further in Section 4. A detailed discussion of the design and construction issues which led to the delays and alterations is given in Section 4.2.

The Section 2.1, following, presents the objectives as they were proposed in the Contract and as they were revised during the course of the Project. Section 2.2 then summarises the extent to which the objectives where achieved.

## 2.1 Objectives Proposed

The objectives under Part A of the Schedule, and which remained current during the course of the contract were;

1. To develop and trial [on-site at an abattoir] intensive, cost effective [covered anaerobic] treatment lagoon technology for removing carbon (in the form of COD, fats, oils and greases) and for control of odour from abattoir wastewater;

2. To document all performance and design data of the successful technology in such a manner as to allow its utilisation and implementation by the Meat Industry for start-up, design, order of magnitude cost estimations and operating cost estimations for future construction;

3. To document options available for utlilisation of biogas at an abattoir;

4. To encourage industry access, interest and involvement in the project and adoption of the technology through education and dissemination seminars;

5. To ensure that the technology is compatible with existing or future abattoir wastewater treatment systems; and

6. To ensure that the technology is cost effective both in terms of capital and operating costs.

In addition to the main objectives above, the Schedule also identified several technical issues to be addressed in the Project and their investigation formed a secondary tier of objectives to be achieved. The technical issues were;

- The fate of fat by varying degrees of treatment, and its likely impact on crust formation and sludge accumulation;

- Mass balance of carbon and phosphorous within the lagoons under each stage of the trial;

- Gas composition, VFA concentration and carbonate/total alkalinity as a function of performance. Also proposed for monitoring operational stability were redox, pH, mixed liquour volatile solids (MLVSS) and VSS;

- Maximum OLR ($kgCOD.m^{-3}.d^{-1}$) and minimum HRT for each stage;

- Sludge yield and the effect of the food to microorganism ratio (F/M) on performance. This will be attempted on the demonstration lagoon but will be more accurately determined in the pilot reactors;

- Lagoon performance as a function of temperature for each stage;

- The effect of sulphate (if appropriate) on lagoon performance;

- An analysis of those scenarios which resulted in crust formation under the cover as well as procedures which can be implemented to reduce crust formation;

- Evaluation of any problems which may arise if the biogas is utilised for heating, cooling, or electrical generation (eg. hydrogen sulphide levels);

- Making sure each stage is stabilised/optimised to make valid comparisons between them. Anaerobic systems are slow to equilibriate, often requiring 2 HRT's to stabilise after changing operating criteria; and

- The most effective method for retrofitting existing lagoons with the most desirable stage.

The Technical Review Committee (TRC 1997, Appendix A) later agreed to some modifications of the extent and content of the technical issues. Some of these changes were required as a result of the problems and delays encountered during design and construction (Section 4.1). Others resulted from the Technical Review Committee's further consideration of the project. The modified technical issues were;

- Mass balance of nitrogen, in addition to carbon and phosphorous, within the lagoons under each stage of the trial;

- Gas production, in addition to composition, to be monitored as a system performance parameter.

- Maximum OLR to be applied to stages 1 and 2 only. Stages 3 and 4 no longer achievable due to cost and time over runs from design/construction stage and resulting under-performance of lagoons.

- A period of 2 to 3 HRT's should be applied for achieving stabilisation between stages, not 2.

## 2.2 Objectives Achieved

Each main objective has been achieved to some degree in the Laboratory Studies and/or the Field Scale Trials. Table 2-1 summarises the six main objectives and the extent to which they were achieved. In each case, failure to reach the ultimate goal was due to the inability of the wastewater main from the abattoir and the influent distribution system to provide the maximum, or a significantly high OLR. All results to date, however, indicate that the objectives could be achieved if the capacity of the wastewater main and distribution system could be increased.

The technical issues, or secondary tier of objectives, proposed in Section 2.1 have also been considered to some extent during laboratory studies and field scale trials. Several of the technical issues, however, could not be fully assessed due to the inability of the lagoons to be loaded to the high organic loading rate desired. Further detailed discussion of these technical issues is provided in Section 4 and 5.

Table 2-1. Summary of Objectives and Level of Achievement

| No. | Objective | Achieved / Status | Goal |
|---|---|---|---|
| 1 | Demonstrate operation of field scale covered anaerobic lagoon | OLR = 0.53 $kgCOD.m^{-3}.d^{-1}$, 88% COD removal and 95% O&G removal. | Demonstrate at maximum organic loading (OLR =1.2 $kgCOD.m^{-3}.d^{-1}$) |
| 2 | Provide design and performance data | Provided for nominal organic loading (OLR = 0.53 $kgCOD.m^{-3}.d^{-1}$) | Obtain for maximum organic loading (OLR =1.2 $kgCOD.m^{-3}.d^{-1}$) |
| 3 | Investigate biogas utilisation | Investigated at maximum OLR achieved in stage 1. (OLR = 0.53 $kgCOD.m^{-3}.d^{-1}$) (Discussed in 8.3) | Investigate at maximum organic loading (OLR =1.2 $kgCOD.m^{-3}.d^{-1}$) |
| 4 | Information dissemination | Industry meetings held and final report provided for stage 1. | Final results and conclusions to be presented to MRC/industry. |
| 5 | Compatibility of technology | Demonstrated at maximum OLR achieved in stage 1. (OLR = 0.53 $kgCOD.m^{-3}.d^{-1}$) | Demonstrate at maximum organic loading (OLR =1.2 $kgCOD.m^{-3}.d^{-1}$) |
| 6 | Demonstrate cost effectiveness | Costs from construction and operation presented. Benefits of Biogas utilisation compared. (Section 8) | Demonstrate at maximum organic loading (OLR =1.2 $kgCOD.m^{-3}.d^{-1}$) |

# 3. PROCESS CONCEPT DESIGN

The process concept design for the field scale trials was developed from the Laboratory Studies (Zhu *et al.*. 1997) in which three basic process concepts were investigated. The nomenclature for each process is based on the method of achieving biomass and substrate contact, viz;

- Contact Process,
- Mechanical Mixing Process, and
- Fixed Film Process.

Each concept was based on a two zone reactor. The first and smaller zone was designated a high activity zone in which biomass/substrate mixing is enhanced by one of the above three processes. The second and larger zone acted primarily as a settling volume.

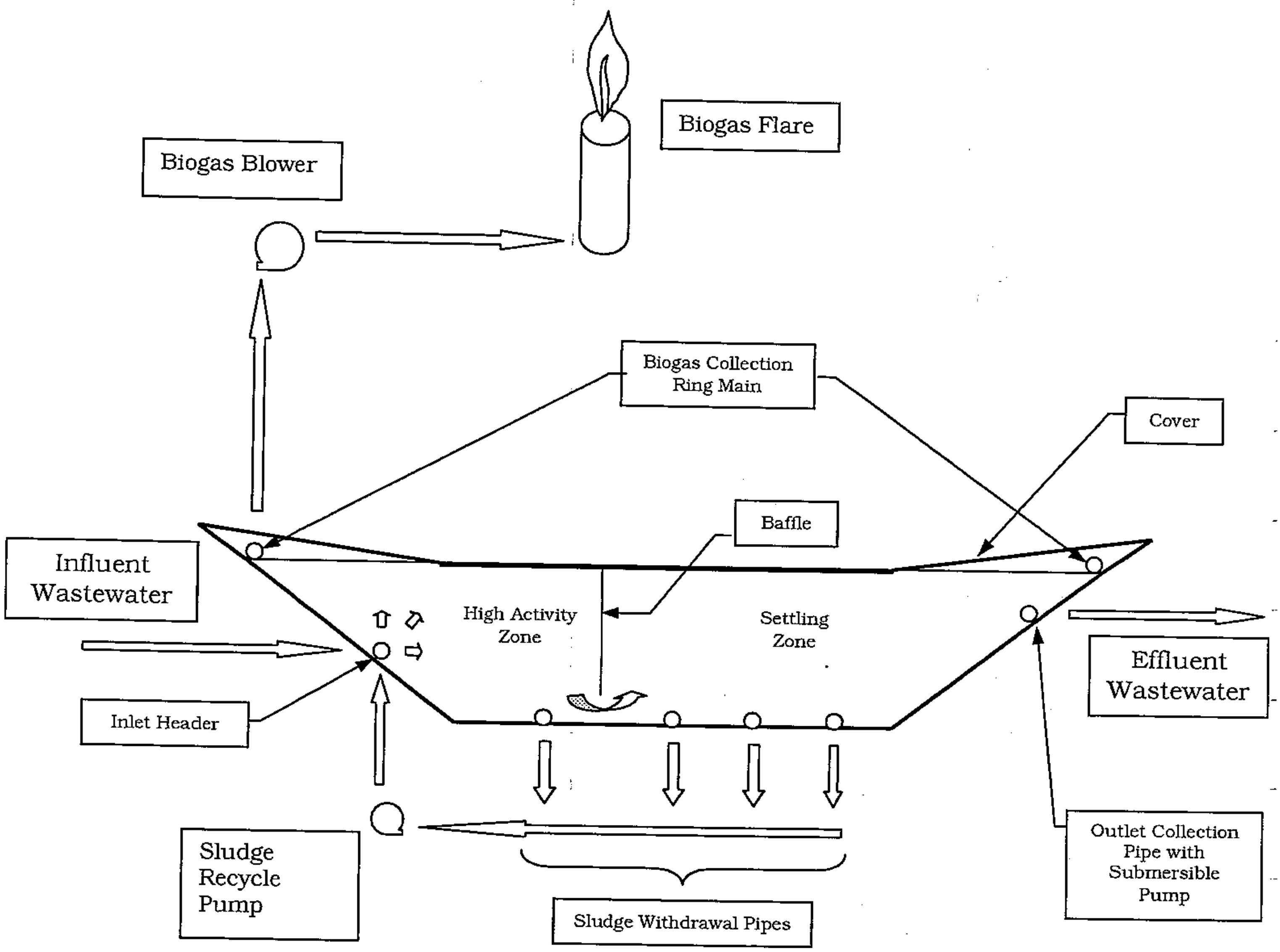
The field scale lagoon was designed on the basis of the "Contact Process" which is illustrated schematically in Figure 3-1. The design included inlet and outlet header pipes which were aimed at providing an even inflow and draw-off from the lagoons. Also included was an ability to recycle sludge from either the high activity zone or the settling zone back to the lagoon influent. A simple baffle, with flow path at the bottom of the lagoon, was proposed as the method for achieving the two zones in the lagoon. The volumetric ratio of high activity zone to settling zone was 1:2.

It is proposed that both zones could be covered for biogas collection and odour reduction. Results from the laboratory studies suggested that covering the first zone only, would be effective in collecting 80 – 90 % of the biogas produced and reduce the bulk of the odours.

For the field scale trials a flexible cover which covered the whole lagoon was installed. A ring main was installed under the cover for biogas collection and a blower fed the biogas to a flare for disposal.

It was proposed that the demonstration of the basic contact process would take place in the first two stages of the field trials (Stage 1: Seeding and Stabilisation, Stage 2: Operation at high OLR). Later modifications would then be made to upgrade the lagoons for demonstration of mechanical mixing, fixed film and partial covering concepts in Stages 3 and 4. As discussed further in Section 4, however, only Stage 1 has been achieved to date and Stage 2 is the subject of continuing research in 1998. The mechanical mixing concept has been abandoned and the fixed film and partial covering stages have been postponed (see Section 4 for details).

Figure 3-1. Process Schematic of Lagoon 1
(Covered Anaerobic Lagoon)



# 4. FIELD SCALE OPERATIONS

The methodology for the field scale trials consisted of a construction stage followed by four operating stages as shown in Table 4-1. For each operating stage it was proposed that an operating schedule and sampling and analysis schedules be prepared and put into place.

Section 4.1 discusses the extent to which this methodology was applied and this is followed by several sections (4.2, 4.3, 4.4 & 4.6) which discuss in more detail the methodology applied to the construction stage, including design, and the only operating stage to be achieved, Stage 1. Section 4.5 discusses the methodology proposed for the pilot scale reactor which was built to replace Stage 4. Appendix D provides a summary of the design, construction and operating milestones.

## 4.1 Operational Methodology

Each of the stages listed in Table 4-1 had first been demonstrated at laboratory scale. Table 4-2 lists the stages and the corresponding laboratory reactors. For a summary of results from the Laboratory Studies see Section 1.3.2, details can be found in the final report of the Laboratory Studies (Zhu *et al.* 1997).

Table 4-1. Stages of Field Scale Trials

| Stage | Description | Comments | Status |
|---|---|---|---|
| Construction | Two 39x29x6m lagoons with inlet flow distribution. | Lagoon 1 with cover and baffle. Lagoon 2 with no cover nor baffle. | Completed. |
| Stage 1 (Start-up & stabilisation) | Lagoon 1 with no sludge recycle. Lagoon 2 with no sludge recycle. | Side by side trial of the benefit of a covered anaerobic lagoon. Initial loading rate 0.35 $kgCOD.m^{-3}.d^{-1}$, then 0.5 - 0.7. | Completed. |
| Stage 2 (Contact process & recycle) | Lagoon 1 with 25, 50 & 100% sludge recycle. Lagoon 2 with no sludge recycle. | Asses benefits of sludge recycle at optimal loading rates. | Proposed for 1998. |
| Stage 3 (Mechanical mixing) | Lagoon 1 with zone 1 mixing & sludge recycle. Lagoon 2 with no sludge recycle. | Demonstrate the advantage of mixing the high activity zone (zone 1) at two levels of sludge recycle. | Omitted. |
| Stage 4 (Fixed film) | Lagoon 1 with zone 1 mixing & sludge recycle. Lagoon 2 with fixed film biomass in zone 1. | Demonstrate the advantage of a fixed film biomass support in the high activity zone (zone 1). | Postponed, Pilot scale reactor developed. |

The decision to proceed from one stage to the next was made by the Technical Review Committee, based on milestones achieved. Due to various problems encountered during design and construction, commissioning of the lagoons was significantly delayed. By the time of commissioning (January 1997), it was proposed that Stage 1 and 2 could be achieved within the remaining time and budget constraints (TRC 1997) and that this would be the minimum required to successfully demonstrate the technology. During the year, however, further operating restrictions stemming from design and construction problems meant only Stage 1 was achieved.

Table 4-2. Field Scale Stage and Corresponding Laboratory Reactor

| Stage Description | Field Scale Stage | Laboratory Reactor |
|---|---|---|
| Start-up & stabilsation (as contact process) | Stage 1 | Reactor 3 |
| Contact process with sludge recycle (0 to 25%) | Stage 2 | Reactor 3 |
| Mechanical Mixing | Stage 3 | Reactor 1 |
| Fixed Film | Stage 4 | Reactor 2 |

Based on the good results achieved during Stage 1 (start-up) however, a Proposal for Project Continuation in 1998 was submitted to the MRC (Appendix B).This Proposal recommended that extending the project to allow Stage 2 (recycle) to be achieved is worthwhile and, in fact, essential for the achievement of meaningful results.

A proposal to omit Stage 3 (mechanical mixing) was presented to the Technical Review Committee on the basis that Laboratory Study results of this operating regime suggested it would not be beneficial to the lagoon's performance. The impending limits on the project budget, due to problems encountered during design and construction, also added to the need to reduce the extent of field scale trials. The Technical Review Committee agreed and Stage 3 was omitted (TRC 1997, Appendix A).

The operating regime of Stage 4 (fixed film) shows the most potential based on Laboratory Studies and its demonstration remains an ultimate goal in the development of this technology. Due to the restrictions on budget and time, however, Stage 4 could not be achieved and the Technical Review Committee has agreed to postpone Stage 4 to a possible future project (TRC 1997, Appendix A).

To compensate for the postponement of Stage 4, a fixed film pilot scale reactor was constructed on-site at Southern Meats to be run in conjunction with the field scale trials. Due to the operational difficulties with the field scale trials, however, the pilot plant has not been fully commissioned. A proposal for the completion of commissioning and running of trials on the pilot scale fixed film reactor has been included in the Proposal for Project Continuation in 1998 (Appendix B).

## 4.2 Design and Construction

The MRC took responsibility for supplying the two field scale lagoons as per Part D of the Contract's Schedule and subsequently contracted Sinclair Knight Merz (SKM) to undertake the detailed design and construction of the lagoons (Agreement M.665B). While having no direct involvement in this contract, the CRC for Waste Management and Pollution Control provided the concept design (Section 3) on which SKM based their detailed design.

### *4.2.1 Detailed Design*

The design was based around two field scale lagoons and the four operating stages (as per Table 4-1) to enable the demonstration of the advanced lagoon configurations and operating regimes which were demonstrated at laboratory scale. As already mentioned, however, Stage 3 (mechanical mixing) was omitted from the trials and was not considered in the design.

The uncovered lagoon (Lagoon 2, Photo 1) was to be used as a control lagoon and the covered lagoon (Lagoon 1, Photo 2) was to be used for the field experiments for Stages 1 and 2. For Stage 4, it was proposed that Lagoon 2 be modified to include a fixed film component in the inlet end of the lagoon, with Lagoon 1 (the covered lagoon) becoming the control using the data from Stages 1 and 2 as an established baseline. As already indicated, however, Stage 4 has been postponed.

A general outline of the concept design is provided in the scope of work for the design and construction contract which included;

- Two earthen lagoons having internal dimensions of 29 m (width) x 39 m (length) x 6 m (depth) (Photo 3 & 4) with trench for cover installation (Photo 5);
- A hypalon cover on one of the lagoons (Photo 2), complete with access manholes, sampling points, provision for sludge withdrawal and recirculation (Photo 6) and a biogas collection ring main (Photo 7);
- A flexible internal baffle across the full width of the covered lagoon allowing a one metre space immediately above the lagoon floor (Photo 7);
- Influent pipework connecting from the inlet to the existing anaerobic lagoon to the inlet to the new lagoons with header for even distribution (Photo 6);
- Effluent pipework returning treated effluent back to the outlet pit of the existing anaerobic lagoon;
- Gas collection pipework for the collection, flow and methane content monitoring of the lagoon gas collected from the covered lagoon (Photo 7 & 8); and
- Burner facilities for the disposal of biogas (Photo 8).

The basic design parameters for the two trial lagoons are presented in Table 4-3. For more generic design data see Section 6.

Other features of the lagoons' design includes;

- A rainwater sump pump on the cover of Lagoon 1;
- The biogas flare system operated on Lagoon 1 cover pressure;
- A flow meter on the influent line to each lagoon;
- A float switch on each lagoon to control lagoon level and effluent pumps; and
- Inlet distribution pipework which provides a flexible distribution of recycled sludge.

Layout and design details of the Southern Meats Lagoon, Lagoon 1 and Lagoon 2 are shown on Drawings H0227/000-1, H0227/000-2 and H0227/000-3 which are included in the Operating Manual provided by Pacific Lining Company (Appendix E).

Table 4-3. Primary Concept Design Parameters of Field Scale Anaerobic Lagoons

| Parameter | Units | Covered Anaerobic Lagoon (Lagoon 1) | Uncovered Anaerobic Lagoon (Lagoon 2) |
|---|---|---|---|
| Capacity | $m^3$ | 3000 | 3000 |
| Capacity of High Activity Zone | $m^3$ | 1188 | N/A(1) |
| Surface Area | $m^2$ | 39 x 29 = 1,131 | 39 x 29 = 1,131 |
| Depth | m | 6 | 6 |
| Sludge Recycle | % | 25 | N/A |
| Influent Temperature | $^oC$ | 35 | 35 |
| Design OLR | $kgCOD.m^{-3}.d^{-1}$ | 0.5 – 1.4 | 0.5 – 0.8 |
| Biogas flow @ design OLR | $m^3.h^{-1}$ @ STP | 20 – 95 | N/A |
| Influent flow rate @ design OLR | $m^3.d^{-1}$ | 250 – 700 | 250 – 400 |
| Structure | - | Earthen dam | Earthen dam |
| Cover Material | - | Hypalon | - |

(1) Not Apllicable

**Photo 1. General View Lagoon 2**

**Photo 2. General View of Lagoon 1 with hypalon cover**

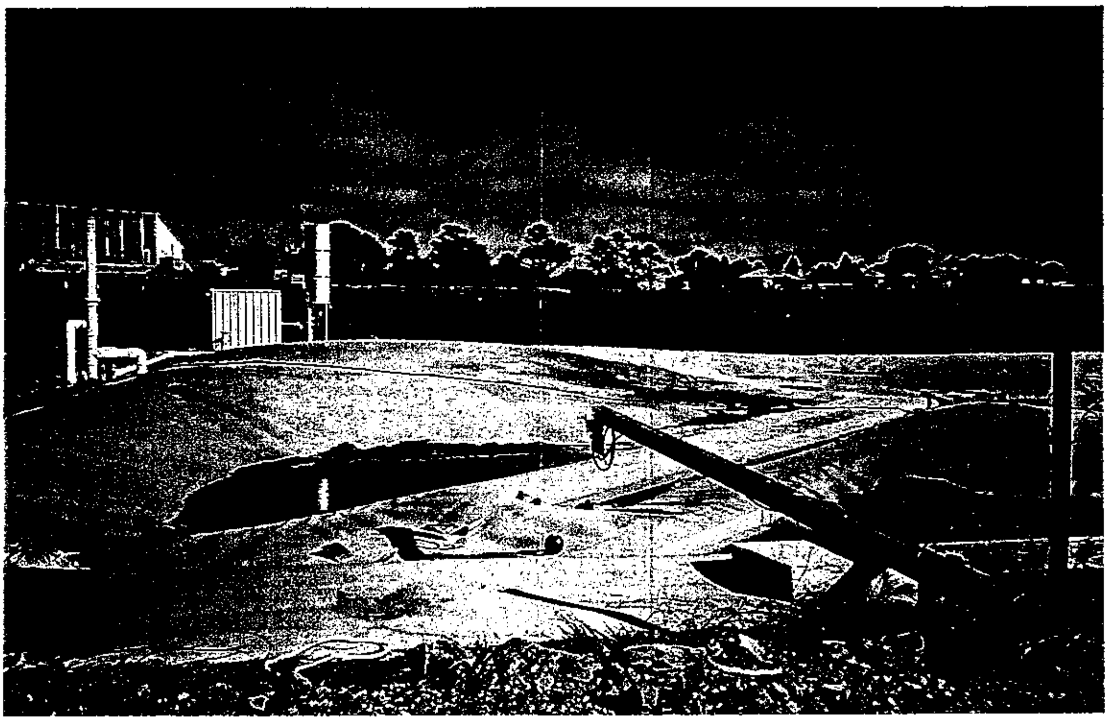


**Photo 3. General View of Lagoons Prior to filling**

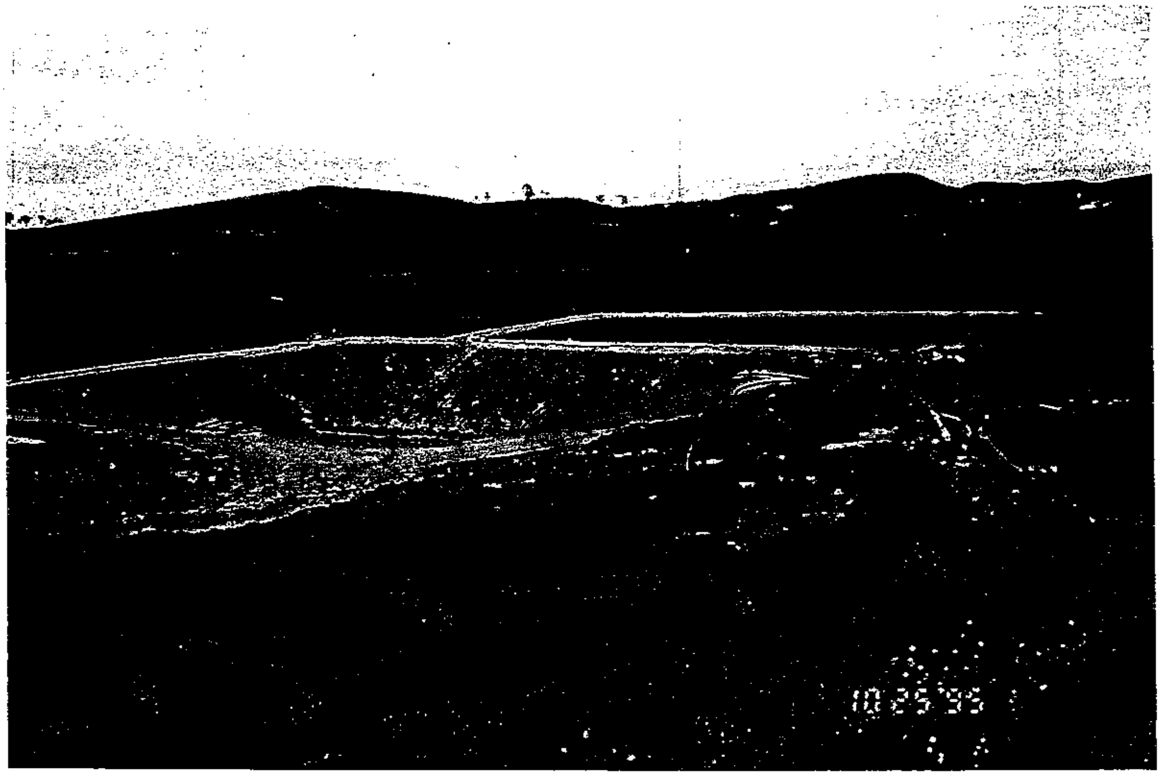


**Photo 4. General View of Lagoons after filling**

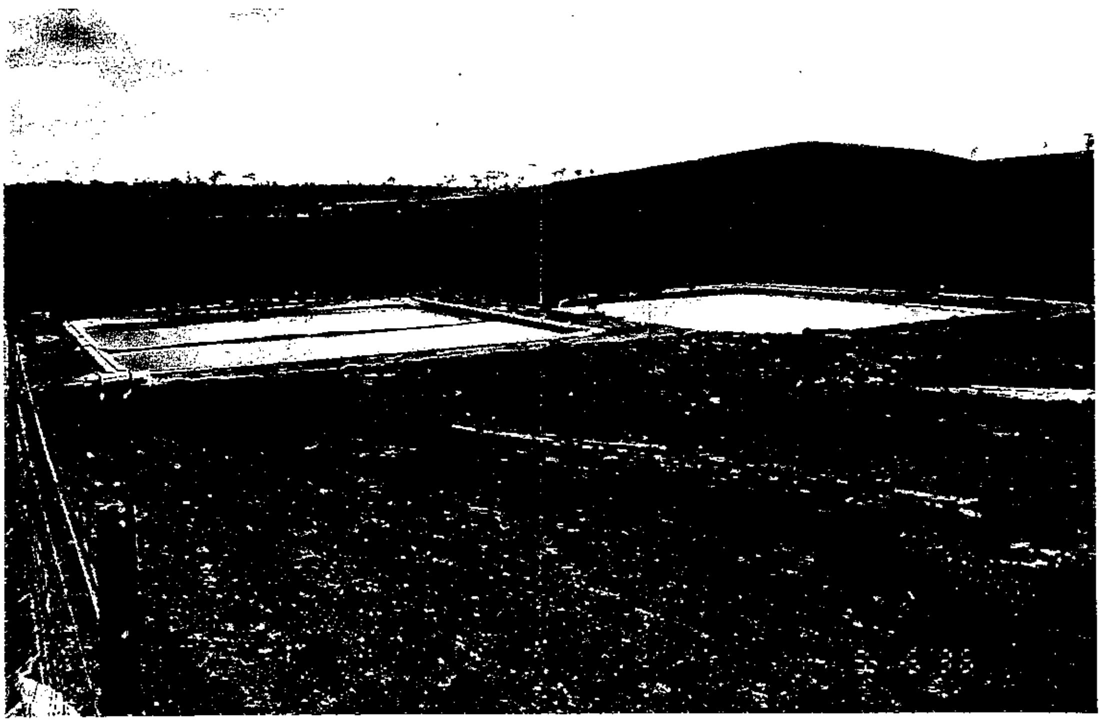


**Photo 5. View of Lagoon 1 showing preparation for cover installation**

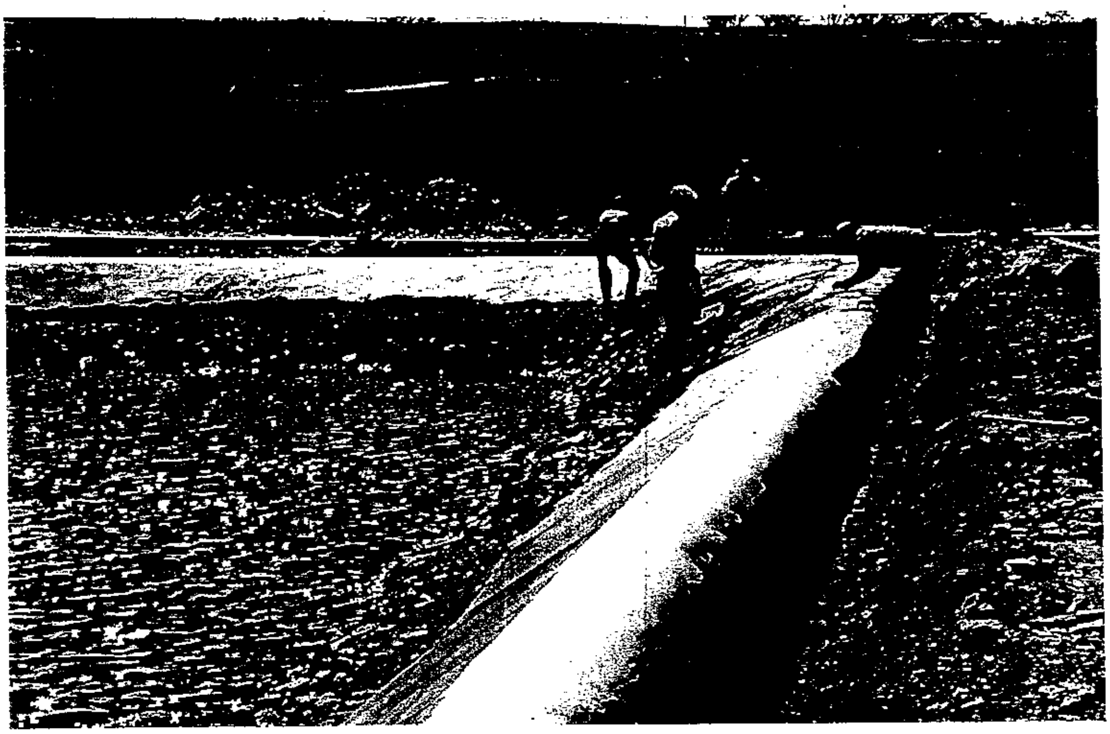


**Photo 6. General View of Lagoon 1 showing sludge withdrawal pipework and inlet header**

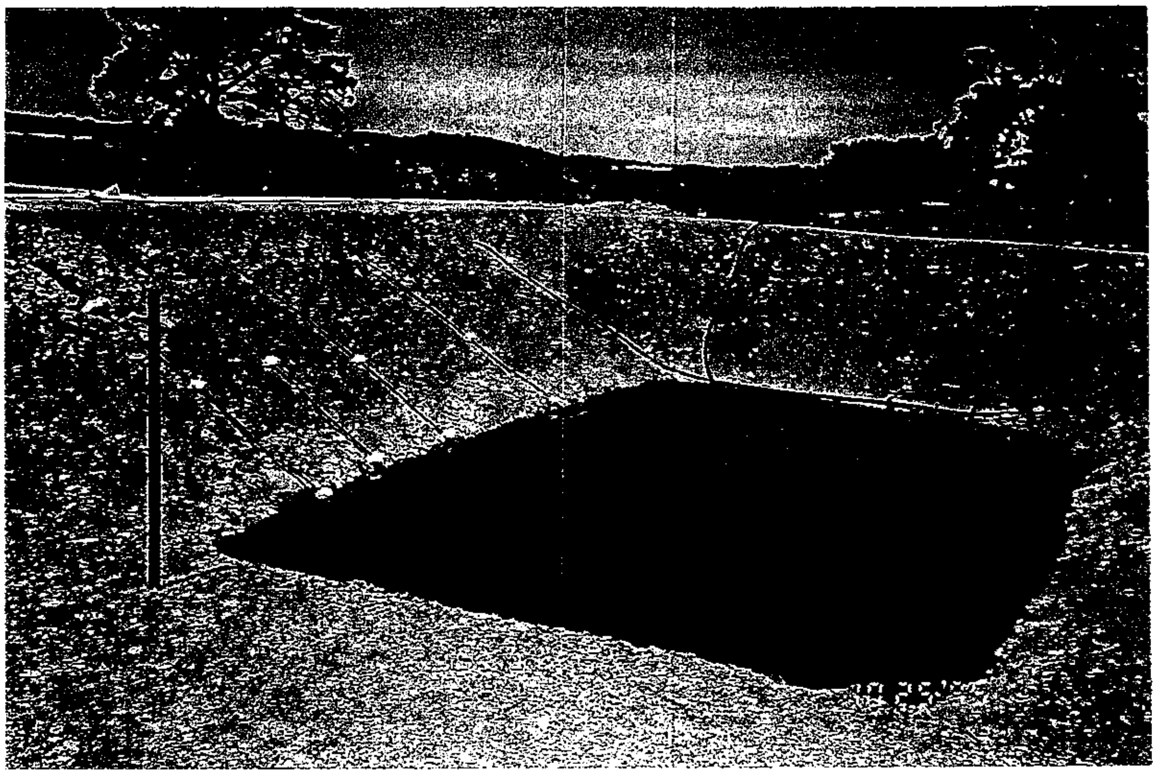


**Photo 7. View of Lagoon 1 showing baffle (centre) and biogas collection header (perimeter of lagoon) prior to cover installation**

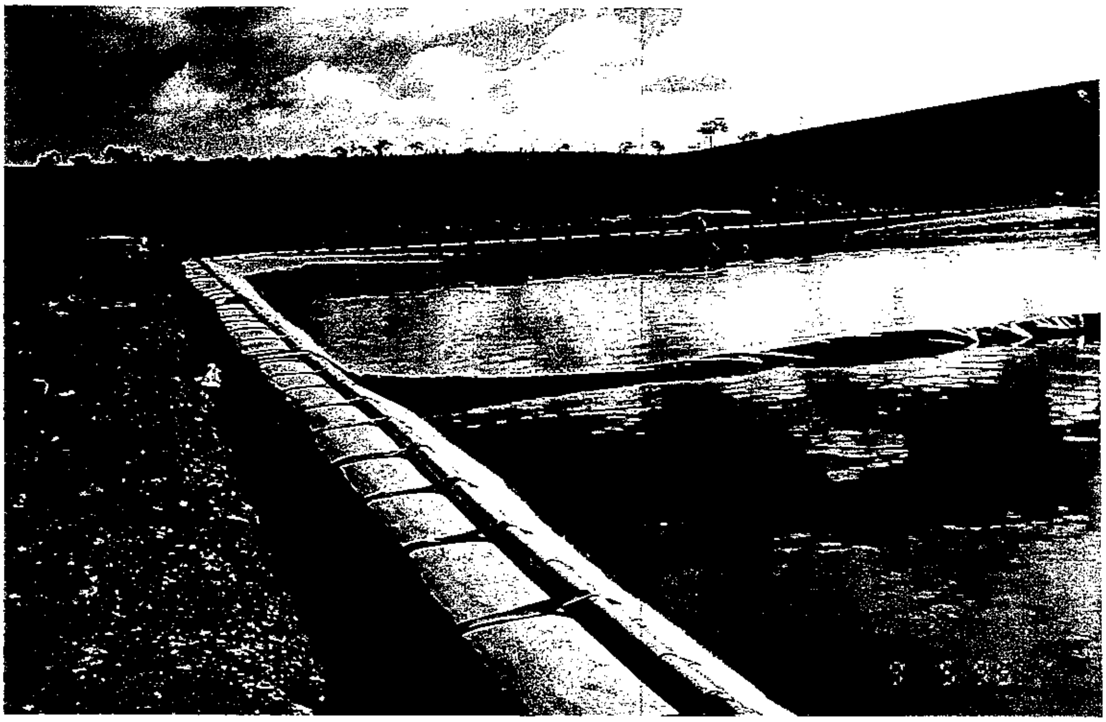
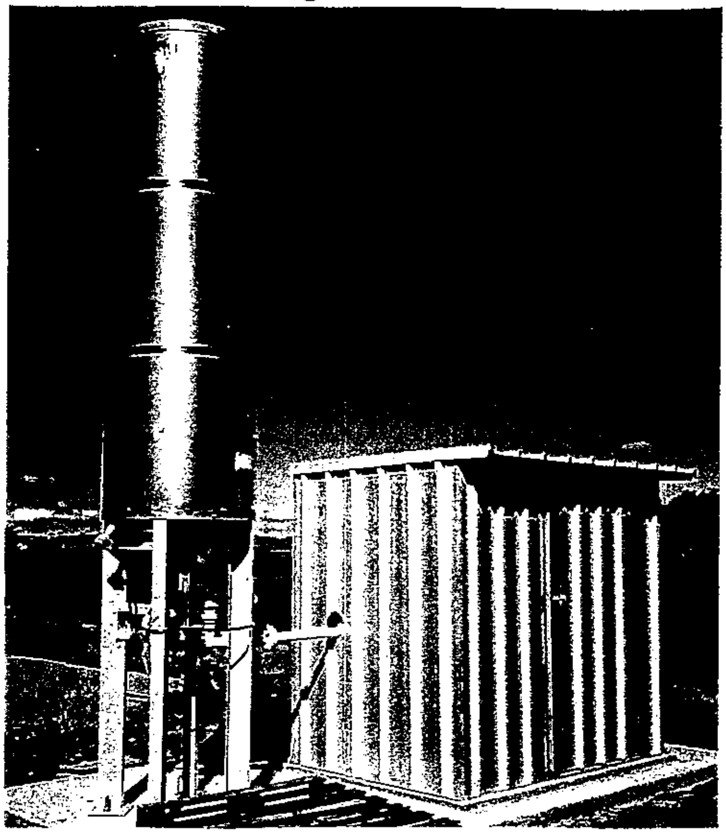


**Photo 8. General View of Biogas Flare and Control Shed**



### *4.2.2 Construction and Commissioning History*

Despite commencing in early 1995, excavation of the two trial lagoons (Photo 1) was not achieved until June 1995 due to weather, labour and planning delays. Details of the geotechnical investigations and civil works are provided in SKM's Construction Report (Appendix F).

The pipework installation experienced delays during the following 6 months and concerns where also raised by the CRC and Southern Meats over the inadequate hydraulic capacity of the pipework system. In November 1995, however, the lagoons were seeded with municipal digester sludge from Goulburn STP, pre-empting the completion of the pipework and in preparedness for the construction of the cover on Lagoon 1.

Despite the cover arriving from the USA in October 1995, completion of the cover installation was not achieved until late 1996. In November 1996 tests were carried out by UNSW, which suggested minimal biomass activity remained and that re-seeding would be required (see Section 4.3).

The inadequate hydraulic capacity of the lagoons can be put down to two factors; blockages in the pipework and small pipe diameter. The latter point meant that the hydraulic capacity of the pipework was too small and the small diameter also exacerbated the problem of blockages due to gross solids, fats and grease in the wastewater.

In January 1997 the lagoons where commissioned, although several outstanding issues remained. It was still not clear whether the distribution system would allow sufficient wastewater flow for operation of the lagoons at the high loads to be trialled (OLR = 1.0 – 1.2 $kgCOD.m^{-3}.d^{-1}$). In addition, the gas collection and flare equipment had not been installed. However, the lagoons where able to be loaded at nominal values (OLR = 0.2 – 0.5 $kgCOD.m^{-3}.d^{-1}$) and this allowed the start-up stage to commence (see Section 4.3).

The gas collection and flare equipment was installed during early 1997 with commissioning completed on 24 June 1997 (Photo 6).

### 4.3 Operating Schedule

As discussed previously (Section 4.1), it was proposed that only the first two of the four stages in the original methodology where to be attempted in the current project due to time and budget constraints. The detailed operating schedule proposed for the first two stages only is thus presented in Table 4-4.

Stage 1 represents a commissioning stage involving start-up and stabilisation periods, while Stage 2 was aimed at demonstrating the improved performance of a covered anaerobic lagoon, over a standard uncovered lagoon, using a basic "contact process" operation and assessing the benefits of sludge recycle. Further commissioning and operating problems, however, resulted in only Stage 1 being achieved to date and Table 4-4 outlines the actual operating schedule applied during this stage. The following sections describe the operating schedule applied during each of the stages listed in Table 4-4. A summary of operating milestones is included in Appendix D.

Table 4-4. Proposed Operating Schedule for Field Scale Lagoons (as per TRC meeting February 1997, Appendix A)

| Stage | Description | Week | Organic Loading Rate ($kgCOD.m^{-3}.d^{-1}$) | |
|---|---|---|---|---|
| | | | Covered Lagoon | Control Lagoon |
| 1-A | Start-up | 1 - 15 | 0.35 - 0.4 | 0.35 – 0.4 |
| 1-B | Stabilisation | 16 - 20 | 0.5 - 0.7 | 0.5 - 0.7 |
| 2 | Recycle | 21 - 27 | 0.8 | 0.8 |
| | | 28 - 32 | 1.0 | 0.6 |
| | | 32 - 36 | 1.2 | 0.4 |

Table 4-5. Operating Schedule Achieved for Field Scale Lagoons

| Stage | Date | Week | Organic Loading Rate ($kgCOD.m^{-3}.d^{-1}$) | |
|---|---|---|---|---|
| | | | Covered Lagoon | Control Lagoon |
| 1 – A (seeding) | 26.3.97 - 9.4.97 | 1 to 2 | - | - |
| 1- B (start-up) | 9.4.97 - 13.5.97 | 3 to 7 | 0.21 | 0.21 |
| 1- C (stabilisation) | 13.5.97 - 28.5.97 | 8 to 9 | 0.41 | 0.49 |
| 1- D (de-bugging) | 28.5.97 - 27.8.97 | 10 to 22 | 0.16 | 0.14 |
| 1- E – 1 (in series) | 27.8.97 - 5.11.97 | 23 to 29 | 0.32 | 0.00 |
| 1- E – 2 (in parallel) | 5.11.97 - 19.11.97 | 30 to 34 | 0.52 | 0.15 |

Note: See Table 5-2 for corresponding HRT and Flow data.

#### 4.3.1 *Stage 1-A : Seeding*

Anaerobic systems generally are renowned for their slow start-up characteristics with anaerobic lagoons being perhaps the slowest where start-up times can be as long as three to six months (Ross *et al.*, 1992). This is primarily due to the slow growth rates of methanogenic microorganisms. Developing a sufficient level of active biomass, which will provide satisfactory removal of organic material (COD) and carbon conversion to methane, in as short a time as possible is thus the main objective of the start-up period.

Traditionally, biomass development in anaerobic lagoons is initially achieved by injecting an inoculum and then allowing the natural metabolic growth of to build up the level of active biomass. During this period wastewater is fed to the lagoon at a low loading rate (0.2 - 0.4 $kgCOD.m^{-3}.d^{-1}$) to provide sufficient substrate for the growing biomass. Care must be taken not to over-feed the lagoonwhich may lead to failure. Conversely, under-feeding the lagoon during this time will lead to a slow biomass growth rate and extended start-up period. Monitoring parameters such as VFA, alkalinity and pH was critical in ensuring the loading rate was satisfactory (refer to Section 4.4.1).

The inoculum used is usually an anaerobic sludge from another existing lagoon. Ideally, this lagoon should be treating a similar waste stream. In most cases, however, anaerobic digesters from local municipal sewage treatment plants (STP) are the most convenient source of such sludge.

During the laboratory study, two start-up periods where experienced and they can be described as follows;

1) First start-up

| | |
|---|---|
| Seed source | : sludge from Southern Meat's existing anaerobic lagoon |
| Seed VSS | : 13,500 $mg.L^{-1}$ |
| MLVSS[1] | : 2,500 $mg.L^{-1}$ |
| Comments | : membrane filtration/recycle technique used to boost biomass development, stable operation achieved within 6 weeks. |

2) Second start-up

| | |
|---|---|
| Seed source | : sludge from Goulburn STP's anaerobic digester |
| Seed VSS | : 15,000 $mg.L^{-1}$ |
| MLVSS | : 4,500 $mg.L^{-1}$ |
| Comments | : close to operating MLVSS, stable operation achieved within 2 weeks. |

The conclusion from the laboratory study was that the membrane filtration/ recycle technique did indeed boost biomass development and reduced the time normally taken to start-up anaerobic reactors. The second start-up showed the advantage of having an operational level of MLVSS from the start, although at full scale this would require a significant volume of seed sludge to be acquired and transported.

Approximately 625 $m^3$ of sludge from Goulburn STP's anaerobic digester and 720 $m^3$ of sludge from the existing anaerobic lagoon was added to the two trial lagoons in November 1995. It was calculated that this inoculum would

[1] MLVSS = mixed liquor volatile suspended solids representing total VSS (sludge and liquid) in total lagoon volume.

give each lagoon a MLVSS of approximately 5,000 mg.L$^{-1}$. Due to the inability to maintain sufficient wastewater flows to the lagoons during 1996, however, the biomass did not remain active. At the time of start-up of the field scale lagoons (March 1997) it was estimated that the MLVSS's of Lagoon 1 and Lagoon 2 were 252 mg.L$^{-1}$ and 333 mg.L$^{-1}$, respectively. Consequently, re-seeding was required.

The re-seeding was carried out over a period of 2 weeks from 26$^{th}$ March to 9$^{th}$ April 1997 using three sources of inoculum, viz; sludge from Goulburn STP's anaerobic digester, sludge from the existing anaerobic lagoon at Southern Meats and waste paunch material collected from the wastewater pre-treatment screens. Less than 5 m$^3$ of the waste paunch material was added to Lagoon 2. It was highly fibrous and largely remained floating on the lagoon surface adding to the scum layer which formed on the lagoon, contributing little to the seeding of the lagoon. It was consequently decided to cease adding this material.

Due to the simplicity of obtaining the STP digester sludge (via road tanker), that was the main inoculum used. Extracting sludge from the existing lagoon at Southern Meats proved to be difficult due to the hard crust on the lagoon and depth required to obtain a suitable sludge. It is recommended, however, that this source of sludge would be more beneficial and all avenues of obtaining it should be investigated in future projects. The volume of each seed sludge applied and associated VSS content are given in Table 4-6. Also shown is the initial and final MLVSS following the three week seeding operation.

As can be seen in Table 4-6, the MLVSS reached about 1,000 mg.L$^{-1}$ in each lagoon. This was significantly lower than desired, but budget constraints on the project and a lack of confidence in the ability of the system to provide more than a low OLR on the lagoons led to the decision to allow the remaining biomass to develop by its own metabolic growth.

To compensate for the low initial MLVSS and help maintain a higher biomass concentration in the high activity zone of Lagoon 1, the sludge recycle pump was operated for 4 hours per day during this stage. This drew sludge from Valve 4 and recycled it back to the inlet header via Valves 7, 11 & 12 (Drawing H227/000-3, Appendix E). This mode of operation represented a maximum recycle rate of 43.2% but, as explained below, the actual recycle rate may have been very much less. No sludge recycling or mixing was carried out on Lagoon 2.

During the initial mode of operation, it became apparent that the sludge recycle pump did not remain primed at all times; due to the low influent flows being used at the time and the poor hydraulics of the wastewater distribution system. Consequently, the inability of the recycle pump to self-prime meant that the pumps performance was severely affected and an estimate of the amount of sludge recycled based on pump run-time is not accurate, but represents the maximum possible.

Table 4-6. Lagoon Start-up MLVSS and Seed Sludge Characteristics

| Lagoon | Initial Lagoon MLVSS (mg.L$^{-1}$) | Goulburn STP Digester Sludge | | Southern Meats Lagoon Sludge | | Trial Lagoon MLVSS (mg.L$^{-1}$) |
|---|---|---|---|---|---|---|
| | | VSS (mg.L$^{-1}$) | Volume (m$^3$)(1) | VSS (mg.L$^{-1}$) | Volume (m$^3$) | |
| 1 | 252 | 14,000 | 150 | 5,800 | 24 | 998 |
| 2 | 333 | 14,000 | 150 | - | - | 1,033 |

(1) Volume added to lagoon

### *4.3.2 Stage 1-B : Start-up*

The aim of the start-up period was to provide a period of consolidation to allow the inoculum to acclimatise and develop into an active biomass. During this stage the aim was to keep the loading on the lagoon relatively low (OLR = 0.35-0.4 kgCOD.m$^{-3}$.d$^{-1}$ and HRT = 17-15 d). Due to a lack of experience with the system in an operating state, however, control settings where underestimated and only a OLR of 0.2 kgCOD.m$^{-3}$.d$^{-1}$ (HRT = 30 d) was achieved (Table 4-5).

Four key parameters of the effluent were measured and used to determine the achievement of a stable biomass, viz;

| | | |
|---|---|---|
| Alkalinity | > | 1,000 mg.L$^{-1}$ |
| VFA | < | 300 mg.L$^{-1}$ |
| pH | = | 6.8 - 7.2 |
| COD | < | 1,500 mg.L$^{-1}$ (representing 75% COD removal) |

With a HRT of 30 days, it was proposed that the lagoons should be operated at Stage 1-B for a period of at least 60 days (representing 2 x HRT). However, within 35 days the lagoons where achieving greater than 75% removal (see Section 5.2) with all other parameters in a satisfactory range and so the next stage was commenced from the end of Week 7 (13th May 1997).

### *4.3.3 Stage 1-C : Stabilisation*

The aim of this stage was to raise and stabilise the OLR to 0.7 kgCOD.m$^{-3}$.d$^{-1}$ for both lagoons, this being the nominal maximum loading achieved by traditional uncovered anaerobic lagoons and representing the base loading of the covered lagoon above which its performance was to be demonstrated. The OLR was to be increased after a nominal period of 2 x HRT, but subject also to satisfactory measurements of the four parameters used in Stage 1-B (VFA, Alkalinity, pH & COD) being recorded.

As can be seen in Table 4-5, however, the OLR only reached 0.42 kgCOD.m$^{-3}$.d$^{-1}$ before the flow to the trial lagoons was stopped. From 20th May 1997 to 26th May 1997 (Week 9) the break tank was removed by Southern Meats personnel in response to over-flow problems at the break tank. The result was that no load was applied to the trial lagoons during week 9.

#### 4.3.4 *Stage 1-D : System De-bugging*

As a result of the break in flow to the trial lagoons, when the lagoons where brought back on line, the loading was kept low to allow the lagoons to recover from a week without organic substrate being provided. The lagoons recovered quickly from this event (see Section 5) and it was proposed that flows could be once again increased to continue the build-up to loads in the order of 0.7 kgCOD.$m^{-3}$.$d^{-1}$.

The new distribution system, without the break tank, however was unable to provide the required volume. Flows of 350 $m^3$.$d^{-1}$ where required to achieve a loading of 0.7 kgCOD.$m^{-3}$.$d^{-1}$, while an average flow of only 67 $m^3$.$d^{-1}$ could be achieved during Week 10 (28th May 1997 to 3rd June 1997).

Consequently, the following 12 weeks (Week 10 to 22, 28th May to 27th August) saw the lagoons being loaded at the low average weekly flow of 77 $m^3$.$d^{-1}$, which corresponds to an OLR of 0.15 kgCOD.$m^{-3}$.$d^{-1}$, while attempts where made to improve the hydraulic capacity of the wastewater supply pipework by operational and minor system changes.

#### 4.3.5 *Stage 1-E : Stabilisation*

By Week 22 (27th August 1997) it had been found that the flow to Lagoon 1 (covered lagoon) may reach 500 $m^3$.$d^{-1}$ with the lagoons operating in series (*ie.* Lagoon 2 receiving the effluent from Lagoon 1). This meant Lagoon 2 would no longer be strictly a control lagoon, however, it would allow Lagoon 1 to be loaded up to an OLR of 1.0 kgCOD.$m^{-3}$.$d^{-1}$ which was the ultimate aim of Stage 1.

From Week 23 to 29 (Stage 1-E-1, 27th August to 5th November) the lagoons were operated in series with Lagoon 1 receiving an average OLR of 0.33 kgCOD.$m^3$.$d^{-1}$. This 7 week period represented 2 x HRT's.

From Week 30 to 34 (Stage 1-E-2, 5th November to 19th November) the loading of Lagoon 1 was increased again to an average OLR of 0.53 kgCOD.$m^3$.$d^{-1}$. This 5 week period represented almost 3 x HRT's. During Stage 1-E-2 several attempts where made at re-introducing parallel operation, while maintaining the load to Lagoon 1. This was not greatly successful but did result in an OLR 0.16 kgCOD.$m^3$.$d^{-1}$ being applied to Lagoon 2 and ensured the biological activity of Lagoon 2 could be maintained at a bare minimum in preparation for future operation.

At this point it had become apparent that to achieve reliable operation at loads higher than already achieved would require significant improvements to the operating system. Due to contract, budget and time constraints it was consequently decided by the MRC and CRC to complete the Project at this stage and pursue a continuation of the trials as a separate project (see Appendix B).

Although monitoring of the trial lagoons ceased at the completion of Week 34 (19th November), the operation of the lagoons has been maintained at this level over the Christmas period and into January 1998.

During the period from Week 23 to 29 (Stage 1-E-1, 27th August to 5th November) a "bubble" formed under the cover and subsequent investigation showed it to be formed by the baffle floating to the surface and collecting gas. This is a significant event which will have an impact on the ability to maintain the two zone configuration in the covered lagoon. It is estimated that about half the depth of the baffle is floating at the lagoon surface, thus leading to only a 2.5 to 3m baffle and much less hydraulic effectiveness. Appendix H provides a historical record of the "bubble" issue.

## 4.4 Sampling and Analysis Schedules

Two main schedules of sampling and analysis where instigated to monitor the status and performance of the lagoons. The first schedule was aimed at providing regular data on the status of the lagoons and allowing accurate control of the lagoon's performance. The second schedule involved a more extensive array of analyses which where done off-site and used to assess, in detail, how the lagoons where behaving.

The schedules are considered separately in the following two sections. Appendix C provides detailed information on the methods of analysis used during the trials. In most cases APHA Standard Methods were used, however, for some particular analyses alternative methods where developed and applied.

### *4.4.1 Operating Analytical Schedule*

A range of parameters, listed in Table 4-7, were measured to allow constant monitoring of the lagoons' status and accurate control of the lagoons' performance. In particular, it was important that the lagoons were not over-loaded, or under-loaded, during start-up and as the loading was increased up to the starting OLR of 0.5 $kgCOD.m^{-3}.d^{-1}$.

Severely overloading the lagoons would reduce the performance of the lagoons and lead to overloading of downstream treatment processes and a deterioration of final effluent quality. Recovery following an overloading event is slow and would delay trials significantly. Furthermore, it was important that operation of the trial lagoons did not adversely impact on the abattoirs overall treatment system. Results from these tests are presented in Section 5.

The operating analytical schedule itself was also under investigation so that an optimised schedule could be developed for use by industry in future applications of the technology. As well as satisfying operating requirements, this schedule had to include analytical requirements imposed by the NSW EPA under the abattoir's environmental operating license.

Table 4-7. Operating Analytical Schedule

| Parameter | Units | Period of Measurement | Method of Measurement(1) |
|---|---|---|---|
| Influent | | | |
| Flow Rate | $L.s^{-1}$ | Continuous | Magnetic Flow Meter |
| COD | $Mg.L^{-1}$ | Weekly | Hach vials and Spectrometer |
| TSS/VSS | $Mg.L^{-1}$ | Periodically (2) | Gravimetry |
| Alkalinity | $Mg.L^{-1}$ | Periodically | 5 point titration |
| VFA | $Mg.L^{-1}$ | Periodically | 5 point titration |
| pH | - | Weekly | Probe |
| Temperature | °C | Weekly | Hand held probe |
| Effluent | | | |
| COD | $mg.L^{-1}$ | Twice Weekly | Hach vials and Spectrometer |
| TSS/VSS | $mg.L^{-1}$ | Periodically | Gravimetry |
| Alkalinity | $mg.L^{-1}$ | Twice Weekly | 5 point titration |
| VFA | $mg.L^{-1}$ | Twice Weekly | 5 point titration |
| pH | - | Twice Weekly | Probe |
| Other | | | |
| Gas Production | $m^3.h^{-1}$ | Continuous | Magnetic flow meter |

Notes:

(1) Full details of analytical methods are given in Appendix C.

(2) Measurements taken periodically (ie. at significant changes in operating conditions such as flow rate, wastewater composition, number of shifts, sludge recycle setting, etc...)

### *4.4.2 Research Analytical Schedule*

To obtain a complete picture of the lagoons' performance, a more extensive sampling and analysis schedule was undertaken. The analyses included in this schedule are summarised in Table 4-8. The bulk of these analyses were done by the Water Environmental Laboratory, Department of Land and Water Conservation (NSW), while others were carried out at the Centre for Water and Waste Technology as indicated.

The frequency of sampling for these analyses was based on the following;

Weekly : Influent, effluent and sludge (from recycle port),
HRT Period : All other mixed liquor and sludge samples,
OLR Period : Biogas samples, BMP sludge samples,

where "HRT period" represents a sampling frequency equal to the hydraulic retention time and "OLR Period" represents sampling once per each stage of organic loading.

Table 4-8. Research Analytical Schedule

| Parameter | Units | Frequency of Sampling | Method of Analysis(1) | Responsibility |
|---|---|---|---|---|
| COD | $mg.L^{-1}$ | weekly | SM(2)5220 | WEL(3) |
| VFA | $mg.L^{-1}$ | weekly | SM 5560 Org. VA | WEL |
| Alkalinity | $mg.L^{-1}$ | weekly | SM 2320 Alk. | WEL |
| TSS/VSS or TS/VS | $mg.L^{-1}$ or %w/w | weekly | SM 2540 Solids | WEL |
| Ammonia | $mg.L^{-1}$ | weekly | SM 4500 $NH_3$ | WEL |
| Total N | $mg.L^{-1}$ | weekly | SM 4500 $N_{org}$ | WEL |
| NOx | $mg.L^{-1}$ | weekly | SM 4500 $NO_3^-$<br>SM 4500 $NO_2^-$ | WEL |
| Total P | $mg.L^{-1}$ | weekly | SM 4500 P | WEL |
| Oil & Grease | $mg.L^{-1}$ | weekly | Solvent extraction | WEL |
| Lagoon Temperature | ° C | hourly | Probe and data logger | CWWT(4) |
| Gas Analysis ($CH_4$, $CO_2$) | % | periodically | Hand held meter | CWWT |
| Sludge layer | m | periodically | MEX-P SS meter | CWWT |
| Scum layer | m | periodically | Rule | CWWT |

Notes:

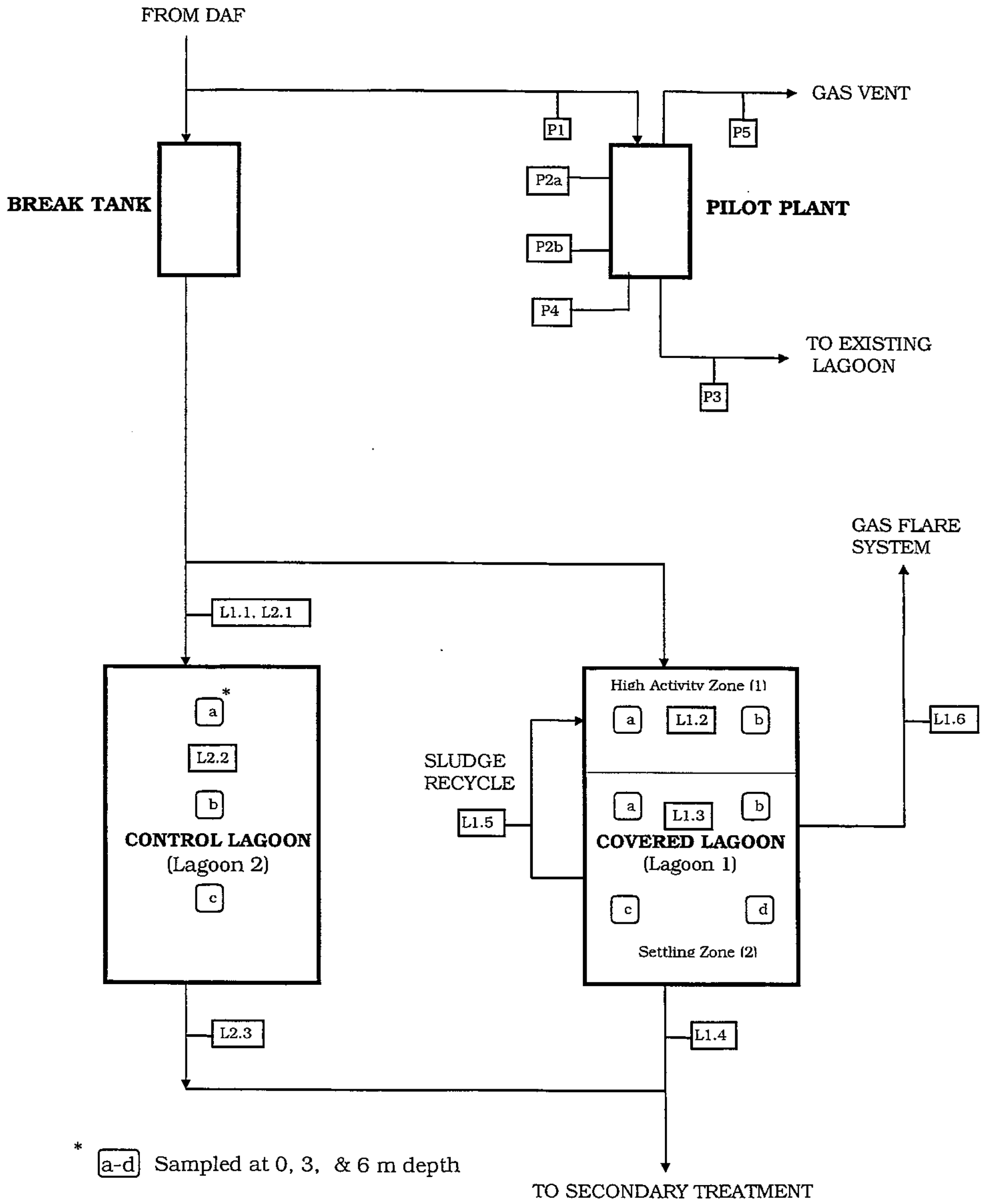
(1) Full details of analytical methods are given in Appendix C
(2) SM - Standard Methods.
(3) WEL - Water Environmental Laboratory.
(4) CWWT - Centre for Water and Waste Technology, UNSW.

### *4.4.3 Sampling Methods*

Sampling was carried out on-site by Southern Meats and CWWT personnel using the sample tapping points and access ports as illustrated in Figure 4-1. At tapping points samples where taken directly into containers to be used for transportation and storage. At access ports a sampling device, which allowed samples to be taken at varying depths, was used and the samples then transferred to transportation/storage bottles.

The type of bottle used for transportation and storage and the methods of pre-treatment used to enhance storage life varied depending on the sample and analysis to be performed. Table 4-9 outlines the container selection and pre-treatment applied in these trials.

## Figure 4-1. Layout of Trial Lagoons and Pilot Reactor Showing Sampling Locations




* [a-d] Sampled at 0, 3, & 6 m depth

Table 4-9. Sample Pre-treatment and Storage

| Analysis | Pre-treatment Applied | Material of Storage Container | Sample Volume Required |
|---|---|---|---|
| COD, Oil & Grease | Acidification to pH < 2, store at 4°C | Glass | 500 mL |
| VFA | freeze | Polyethylene | 250 mL |
| Alkalinity, pH, TSS/VSS | freeze | polyethylene | 1,000 mL |
| Ammonia, Total N, NOx, Total P | freeze | polyethylene | 250 mL |
| Gas Analysis ($CH_4$, $CO_2$) | ambient temperature | teflon bag | ~ 1 L |

## 4.5 Pilot Scale Fixed Film Reactor

The inclusion of fixed film technology into an anaerobic lagoon was investigated at the laboratory scale in the Laboratory Studies (Section 1.3) and was to be demonstrated at full scale in Stage 4 of the field scale trials, as proposed in the original objectives (Section 2). Due to the delays and cost over-runs discussed previously, it was decided that Stage 4 of the field scale trials could not be undertaken within the project's remaining budget and time frame.

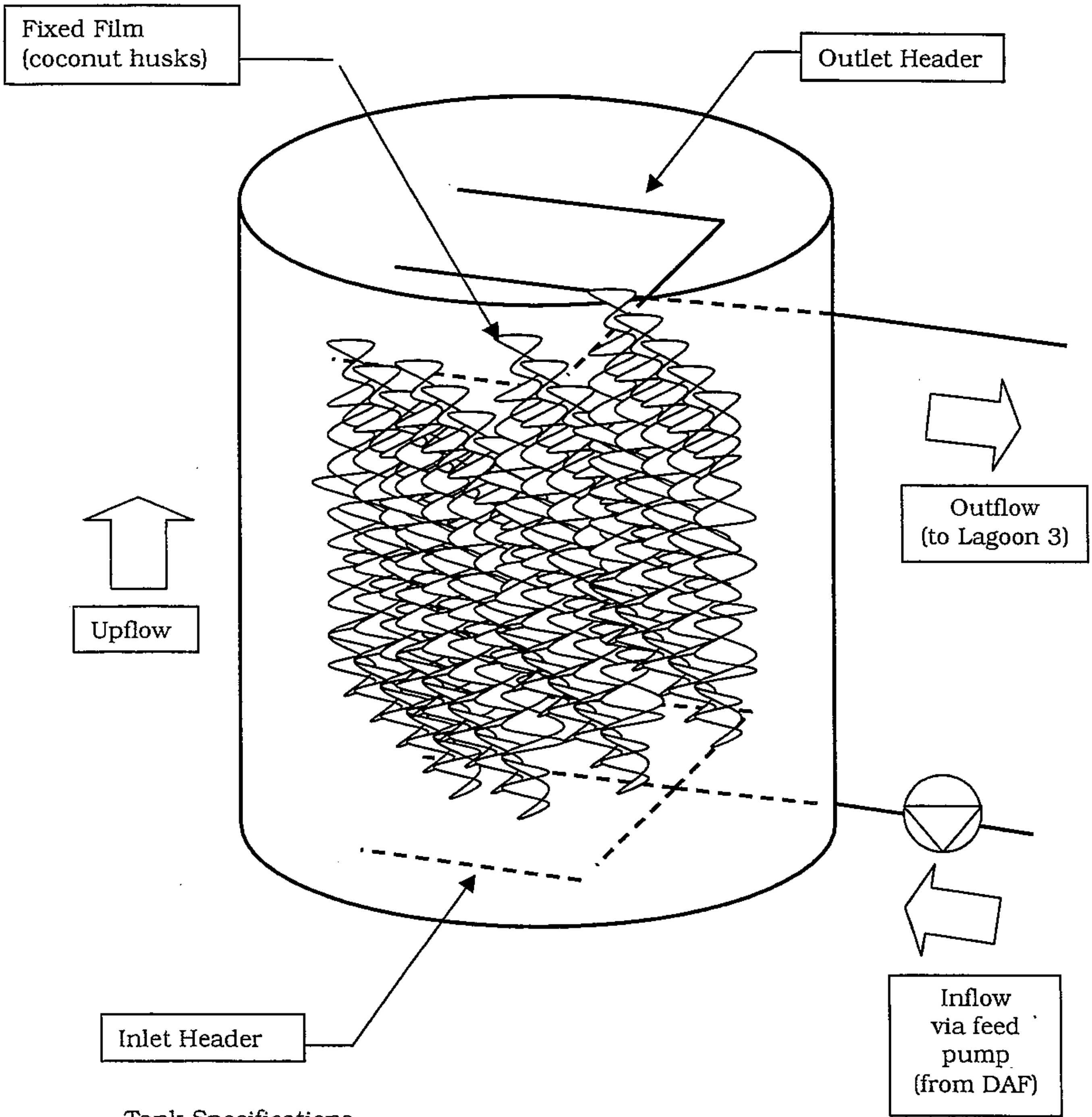
It was proposed, however, that a pilot scale demonstration of the fixed film technology could be met within budget constraints and that this would be a valuable undertaking to ascertain more definitely whether demonstration of such technology should be pursued at full scale. The Technical Review Committee agreed to this proposal in February 1997 (TRC 1997).

### *4.5.1 Fixed Film Pilot Reactor Design*

The fixed film pilot scale reactor was designed at the Centre for Water and Waste Technology (UNSW) and based on Reactor 2 from the Laboratory Studies (Zhu *et al.* 1997). The laboratory reactor consisted of two zones. Zone 1, the high activity zone, included a fixed film while Zone 2 acted as a settling zone. Though it was proposed that the reactor have two zones, the high activity zone (responsible for the majority of the COD removal) was the only zone modelled by the pilot scale reactor.

To create the fixed film, coconut fibre brushes, similar to those used in the Laboratory Studies, were used. Figure 4-2 shows the schematic of the reactor, Table 4-10 gives some basic design parameters and Photo 9 provides a general view of the Pilot Plant.

**Figure 4-2. Pilot Scale Fixed Film Reactor**
(Shown in upflow mode)




Tank Specifications

| | | | |
|---|---|---|---|
| Capacity | : | 1.57 | $m^3$ |
| Diameter | : | 1.0 | m |
| Height | : | 2.0 | m |

Table 4-10. Pilot Fixed Film Reactor

| Design Parameter | Units | Value |
|---|---|---|
| Total Volume | $m^3$ | 1.57 |
| Fixed Film Media | - | coconut husks |
| Fixed Film VSS equivalent(1) | $mg.L^{-1}$ | 6,200 |
| Mixed Liquor VSS | $mg.L^{-1}$ | 4,500 |
| Flow Rate | $m^3.d^{-1}$ | 0.26 - 0.63 |
| Organic Loading Rate | $kgCOD.m^{-3}.d^{-1}$ | 1.0 - 2.4 |
| Hydraulic Retention Time | d | 6.0 - 2.5 |

(1) Based on measurement of fixed film biomass in Laboratory Studies.

### 4.5.2 *Pilot Reactor Construction and Commissioning*

The pilot scale reactor was constructed using the nominal volume achieved by creating a vessel from a concrete pipe of 1m diameter standing end on. The resulting volume was 1.57 $m^3$.

Construction and commissioning of the pilot reactor was undertaken by Southern Meats and CWWT personnel and commenced in 1996. Due to the problems associated with the field scale lagoons, however, start-up of the pilot reactor was not commenced until October/November 1997. Consequently, no meaningful results have been obtained from the pilot reactor to date and it has been proposed that the pilot reactor be operated at Stage 1-A (as per Table 4-10) until re-commencement of trials on field scale lagoons in early 1998.

### 4.5.3 *Pilot Reactor Expected Operation and Performance*

It is expected that the inclusion of fixed film technology will allow significantly greater organic loadings to be achieved while maintaining high COD removal. Consequently, a range of loads are proposed up to as high as 2.4 $kgCOD.m^{-3}.d^{-1}$ with > 75% COD removal expected (Table 4-11). As mentioned previously, the demonstration of this is now proposed to be achieved as part of the project extension (Appendix B).

## 4.6 Technical Review Committee

As part of the CRC's management of the project a Technical Review Committee (TRC) was formed to periodically review the methodology, progress and results of the project. The committee consisted of experts from a range of academic, professional, commercial and institutional backgrounds which is made possible from the wide range of members of the CRC. Table 4-12 lists the members of the TRC.

At the completion of the Laboratory Studies a TRC meeting was convened to review the results of theses studies, progress with field scale lagoon construction and the methodology to be applied to the field scale trials. This meeting was held in February 1997 (see minutes in Appendix A). This meeting set the foundations for the present objectives of the field scale trials.

No meetings of the TRC have been convened since due to the poor progress made with the field scale trials. It is proposed that a TRC meeting be held in March/April to review this Final Draft Report and the operating strategies and methodology for the project continuation.

Table 4-11. Proposed Operating Schedule and Expected Performance for Pilot Fixed Film Reactor

| **Stage** | **Description** | **OLR ($kgCOD.m^{-3}.d^{-1}$)** | **HRT (days)** | **COD Removal (%)** | **Week** |
|---|---|---|---|---|---|
| 1-A | Start-up | 0.5 | 12.0 | ~ 90 | Achieved(1) |
| 1-B | Stabilise | 0.7 | 8.6 | > 85 | 1 – 3 |
| | | 1.0 | 6.0 | > 80 | 4 – 6 |
| 2 | Down-flow Testing | 1.3 | 4.6 | > 80 | 7 – 9 |
| | | 1.6 | 3.8 | ~ 80 | 10 – 12 |
| | | 2.0 | 3.0 | ~ 75 | 13 – 15 |
| | | 2.4 | 2.5 | < 75 | 16 – 18 |
| 3 | Re-Stabilise | 1.3 | 4.6 | > 80 | 19 – 21 |
| 4 | Up-flow Testing | 1.3 | 4.6 | > 80 | 22 – 24 |
| | | 1.6 | 3.8 | ~ 80 | 25 – 27 |
| | | 2.0 | 3.0 | ~ 75 | 28 – 30 |
| | | 2.4 | 2.5 | < 75 | 31 – 33 |

(1) Pilot reactor commenced operation on 8th October 1997 and will be operated at 0.5 $kgCOD.m^{-3}.d^{-1}$ until start of new trials.

Table 4-12. Technical Review Committee Membership

| Name | Organisation |
|---|---|
| Dr David Barnes | Sinclair Knight Merz |
| Dr Brace Boyden | Sinclair Knight Merz (formerly of Aquatec Maxcon) |
| Mr Phil Banks | Sinclair Knight Merz |
| A./Prof Nicholas Ashbolt | Centre for Water & Waste Technology, Civil & Environmental Engineering, UNSW |
| Mr Ian Fergus | CRC for Waste Management & Pollution Control |
| Dr Mike Johns | Chemical Engineering, University of Queensland |
| Mr Peter Spencer | Centre for Water & Waste Technology, Civil & Environmental Engineering, UNSW |
| Former Members | |
| Hong Zhu | Formerly of Centre for Water & Waste Technology, Civil & Environmental Engineering, UNSW |
| Mr. Peter Burnett | Formerly Sinclair Knight Merz |

**Photo 9. General View of Pilot Plant**

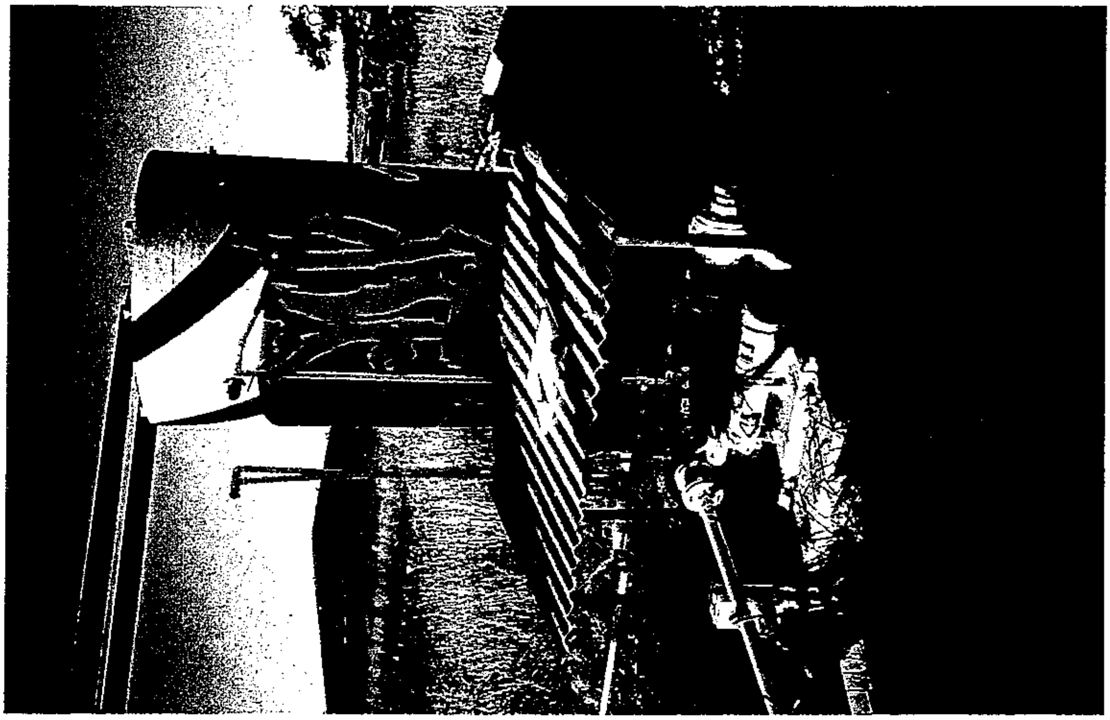
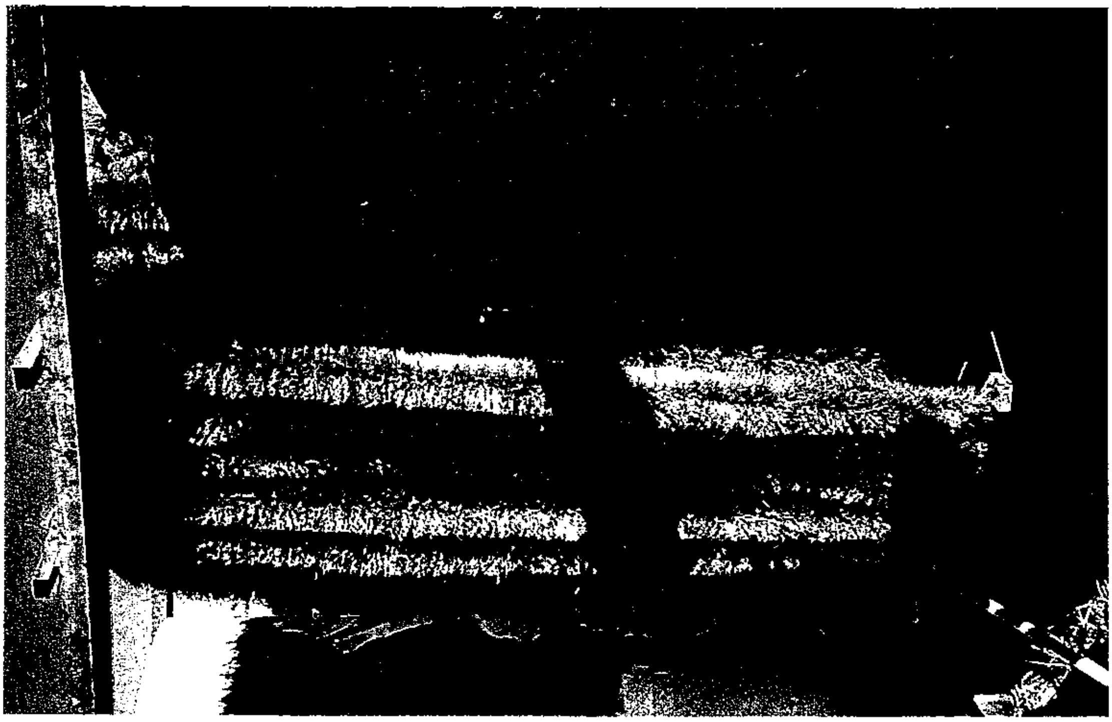


**Photo 10. Coconut fibre brushes used as substrate for fixed film**



# 5. RESULTS

## 5.1 Abattoir Wastewater Characterisation

The nature of wastewater from abattoirs in various locations and processing various meats has been well documented by several researchers and was reviewed in the literature surveys (Section 1.2). Table 5-1 shows a range of wastewater characteristics measured at Southern Meats during the course of this research. For comparison, typical characteristics of Australian abattoir wastewater from Johns (1993) are also presented in Table 5-1.

Generally, the characteristics of Southern Meats' wastewater were similar to that of other operations. Some key differences, however, should be highlighted;

- The level of oil and grease (O&G) in Southern Meats wastewater was significantly higher than the industry norm, with an average level of 1,125 $mg.L^{-1}$ compared to 100 – 200 $mg.L^{-1}$ for industry. This is despite being pre-treated by screens and DAF.
- The levels of nutrients (N & P) were also significantly higher with 280 $mg.L^{-1}$ Total N and 38.6 $mg.L^{-1}$ Tot.al P versus the industry norm of 114 – 148 $mg.L^{-1}$ Total N and 20 – 30 $mg.L^{-1}$ Total P.

Table 5-1. Comparison of Abattoir Wastewater Characteristics

| Parameter ($mg.L^{-1}$) | Typical Abattoir Raw Wastewater (1) (all meats) | Southern Meats Wastewater ex DAF (sheep) | |
|---|---|---|---|
| | | Range | Average |
| BOD | 1,600 – 3,000 | ~ ½ COD (2) | |
| COD | 4,200 – 8,500 | 3,100 – 11,500 | 6,000 (3) |
| O&G | 100 – 200 | 290 – 2,670 | 1,125 |
| TSS | 1,300 – 3,400 | 1,150 – 5,700 | 2,555 |
| VSS | n/a | 1,040 – 5,300 | 2,344 |
| Total N | 114 – 148 | 180 – 440 | 280 |
| NOx | n/a | 0.01 – 0.12 | 0.03 |
| $NH_4$-N | 65 – 87 | 18 – 135 | 55 |
| Total P | 20 – 30 | 26.4 – 60.0 | 38.6 |
| VFA | 175 – 400 | 61 – 600 | 251 |
| Alkalinity | 350 - 800 | 340 – 700 | 486 |

(1) Johns (1993).
(2) From Southern Meats' EPANSW monitoring records.
(3) Weighted average, based on two 24 hour COD sampling runs.

The primary goal of anaerobic treatment is the removal of organic carbon by conversion to methane. For the purposes of this study, and as is the case in industry generally, the level of organic carbon is measured as chemical oxygen demand (COD). Consequently, the measure of COD is critical to assessing the anaerobic lagoon's performance.

The level of COD in the wastewater from Southern Meats varies significantly during the day and so COD analysis of grab samples, along with total flow data, will not provide an accurate indication of the total COD load being placed on the lagoons. Consequently, two separate sampling runs were undertaken where samples were collected each hour for 24 hours.

A weighted average COD figure was calculated, based on the hourly flow at the corresponding time of day. This resulted in an average COD of 6,000 $mg.L^{-1}$ being established as the basis for all organic loading and carbon mass balance calculations. It has been assumed that this average COD level, which is within the range recorded for abattoir wastewaters (Table 5-1), has remained at this level during all field scale trials to date.

## 5.2 Organic and Hydraulic Loading

The organic loading rate (OLR) is calculated as kilograms of COD applied per cubic metre of lagoon volume per day ($kgCOD.m^{-3}.d^{-1}$). The OLR achieved during these trials are summarised in Table 5-2. Also shown in Table 5-2 is the corresponding flow and hydraulic retention time.

The organic loading can also be stated in terms of the kilograms of COD applied per kg of volatile suspended solids in the lagoon per day. The mixed liquor volatile suspended solids (MLVSS) is used for this calculation and using results from Table 5-16, the organic loading stated as $kgCOD.kgVSS^{-1}.d^{-1}$ is shown in Table 5-3.

Figure 5-1 shows a graph of the weekly average flows to the covered and uncovered lagoons.

Table 5-2. Organic Loading Based on Lagoon Volume

| Stage | Week(1) | Covered Lagoon Flow ($m^3.d^{-1}$) | Covered Lagoon HRT (d) | Covered Lagoon OLR ($kgCOD.m^{-3}.d^{-1}$) | Control Lagoon Flow ($m^3.d^{-1}$) | Control Lagoon HRT (d) | Control Lagoon OLR ($kgCOD.m^{-3}.d^{-1}$) |
|---|---|---|---|---|---|---|---|
| 1-B | 3 – 7 | 103 | 29.2 | 0.21 | 103 | 29.2 | 0.21 |
| 1-C | 8 – 9 | 206 | 14.6 | 0.41 | 245 | 12.2 | 0.49 |
| 1-D | 10 – 22 | 80 | 37.5 | 0.16 | 71 | 42.3 | 0.14 |
| 1-E | 23 – 29 | 161 | 18.7 | 0.32 | 0 | - | 0 |
| 1-F | 30 – 34 | 260 | 11.5 | 0.52 | 73 | 41.2 | 0.15 |

(1) Week 3 to 34 = 9 April to 19 November 1997.

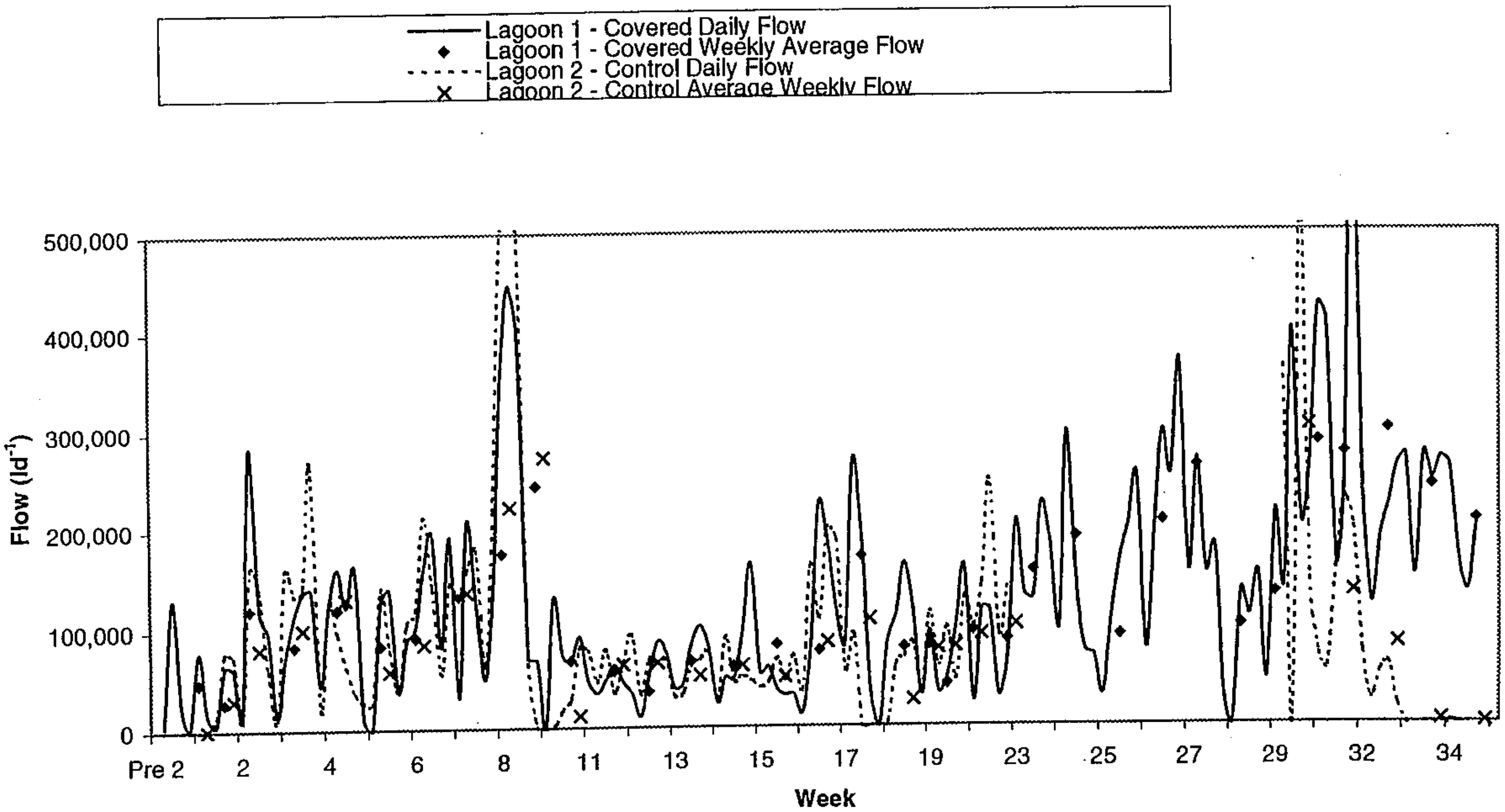
Table 5-3. Organic Loading Based on MLVSS(1)

| Stage | Week(2) | Covered Lagoon Flow ($m^3.d^{-1}$) | Covered Lagoon HRT (d) | Covered Lagoon OLR ($kgCOD.kgVSS^{-1}.d^{-1}$) | Control Lagoon Flow ($m^3.d^{-1}$) | Control Lagoon HRT (d) | Control Lagoon OLR ($kgCOD.kgVSS^{-1}.d^{-1}$) |
|---|---|---|---|---|---|---|---|
| 1-B | 3 – 7 | 103 | 29.2 | 0.298 | 103 | 29.2 | 0.546 |
| 1-C | 8 – 9 | 206 | 14.6 | no data | 245 | 12.2 | no data |
| 1-D | 10 – 22 | 80 | 37.5 | no data | 71 | 42.3 | no data |
| 1-E | 23 – 29 | 161 | 18.7 | 1.171 | 0 | - | no data |
| 1-F | 30 – 34 | 260 | 11.5 | 0.884 | 73 | 41.2 | no data |

(1) MLVSS (mixed liquor volatile suspended solids) of whole lagoon from Table 5-14.

(2) Week 3 to 34 = 9 April to 19 November 1997.

**Figure 5-1. Wastewater Flow**



## 5.3 COD Removal

Organic carbon removal is measured as the reduction of COD from the influent COD to effluent COD. The average influent COD has been assumed to be 6,000 kgCOD.m$^{-3}$.d$^{-1}$ (Table 5-1) and the two trial lagoons have generally produced effluent COD's less than 1000 kgCOD.m$^{-3}$.d$^{-1}$, representing a COD removal of at least 83 %. The COD removal dropped to 79.2 % in the covered lagoon when the maximum OLR of 0.52 kgCOD.m$^{-3}$.d$^{-1}$ was applied.

The average COD removals for each loading stage are summarised in Table 5-4, while Figure 5-2 illustrates the weekly influent and effluent COD levels as recorded by weekly grab samples.

Table 5-4. Organic Carbon Removal by Trial Lagoons

| Week | Covered Lagoon | | | Control Lagoon | | |
|---|---|---|---|---|---|---|
| | OLR (kgCOD.m$^{-3}$.d$^{-1}$) | Effluent COD (mg.L$^{-1}$) | COD Removal (%) | OLR (kgCOD.m$^{-3}$.d$^{-1}$) | Effluent COD (mg.L$^{-1}$) | COD Removal (%) |
| 3 – 7 | 0.21 | 988 | 83.5 | 0.21 | 980 | 83.7 |
| 8 – 9 | 0.41 | 935 | 84.4 | 0.49 | 770 | 87.2 |
| 10 – 22 | 0.16 | 770 | 87.2 | 0.14 | 781 | 87.0 |
| 23 – 29 | 0.32 | 846 | 85.9 | 0.00 | - | 0.0 |
| 30 - 34 | 0.52 | 1246 | 79.2 | 0.15 | 785 | 86.9 |

## 5.4 Gas Production and Analysis

The biogas flare equipment incorporates a vortex gas flowmeter which measures the volume of biogas being flared. The accurate measurement of gas by this flowmeter, however, is restricted to flows above 35 m$^3$.h$^{-1}$. At the low loading rates applied to date, biogas production was only expected to be 10 to 30 m$^3$.h$^{-1}$ and consequently accurate measurement of biogas production has not been possible to date. Biogas production above 35 m$^3$.h$^{-1}$ is expected when higher organic loads are applied to the covered lagoon.

Two site measurements where made of biogas methane ($CH_4$) and carbon dioxide ($CO_2$) composition using a hand-held gas analyser (LFG 20 Landfill Gas Analyser, ADC). The results are shown in Table 5-5.

Table 5-5. On-Site Biogas Composition from Covered Lagoon

| Week | OLR (kgCOD.m$^{-3}$.d$^{-1}$) | $CH_4$ (%) | $CO_2$ (%) | Other (%) |
|---|---|---|---|---|
| 32 | 0.62 | 62.0 | 22.8 | 15.2 |
| 34 | 0.42 | 64.4 | 23.2 | 12.4 |

## 5.5 Oil and Grease

After trialling several analytical methods, a solvent (hexane) extraction method was developed by WEL to measure oil and grease by Week 16 (2.7.97). The method provides a measure of hexane extractables and this is taken as a representation of the oil and grease content of the sample. For details of this method refer to Appendix C.

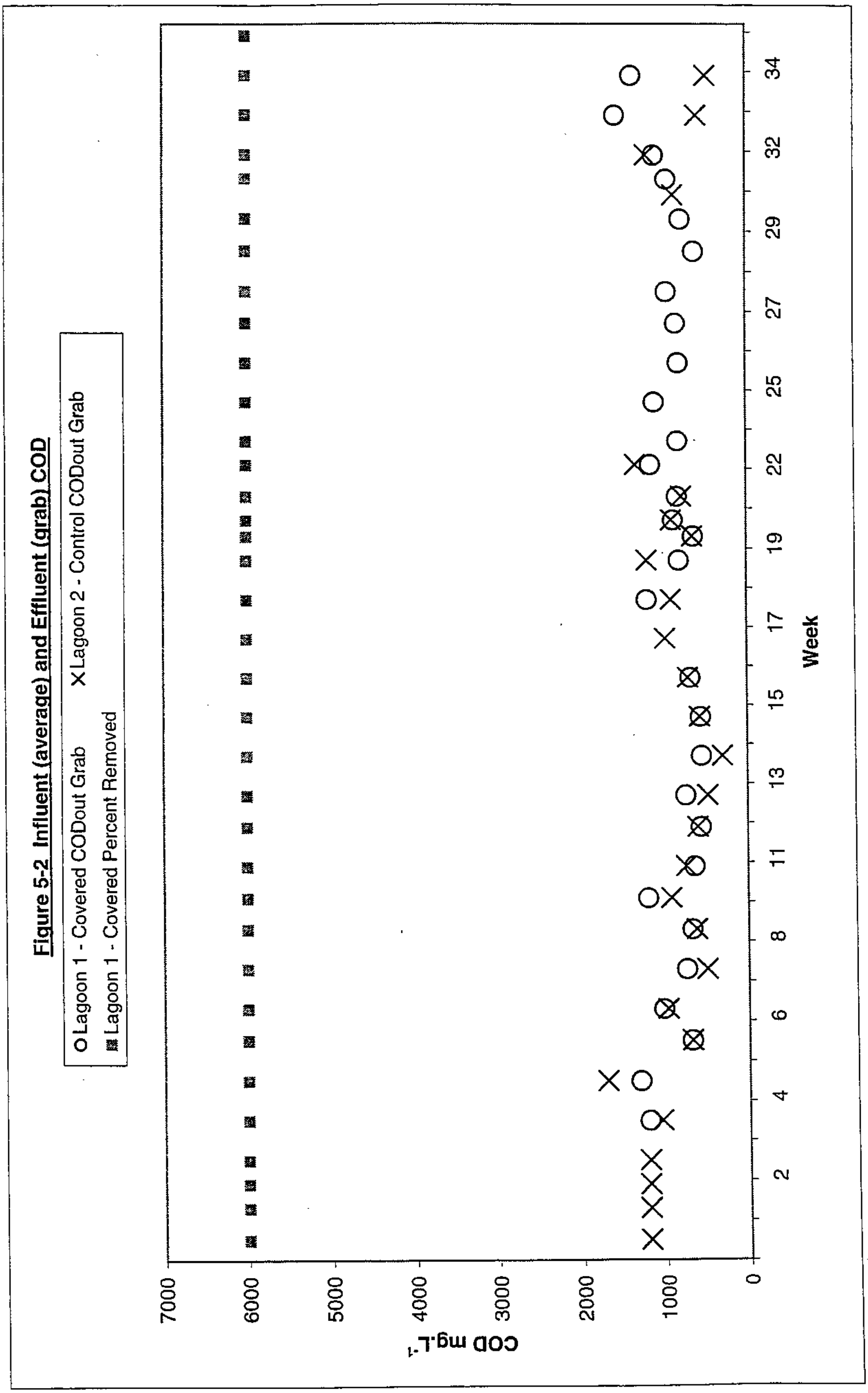



Figure 5-2 Influent (average) and Effluent (grab) COD

The results given in Table 5-6 illustrates the removal of O&G achieved by the lagoons. The influent O&G of 1125 mg.L$^{-1}$ was determined as the average of all influent grab samples and it has been assumed that this average remained constant for the period of the trial. As shown in Table 5-1, this O&G value is within the typical range of values for abattoir wastewaters that have been recorded.

Detailed results by sampling point, including depth, lateral and axial profiling points is given in Appendix G and illustrate the fate of oil and grease within the lagoons.

Table 5-6. Removal of Oil and Grease by Trial Lagoons

| Week | Covered Lagoon | | | Control Lagoon | | |
|---|---|---|---|---|---|---|
| | **HRT (d)** | **Effluent O&G (mg.L$^{-1}$)** | **Removal (%) (1)** | **HRT (d)** | **Effluent O&G (mg.L$^{-1}$)** | **Removal (%) (1)** |
| 3 – 7 | 29.2 | N/A | N/A | 29.2 | N/A | N/A |
| 8 – 9 | 14.6 | N/A | N/A | 12.2 | N/A | N/A |
| 10 – 22 | 37.5 | 76 (45-120) | 93.2 | 42.3 | 86 (45-140) | 92.3 |
| 23 – 29 | 18.7 | 47 (15-70) | 95.8 | - | 30 (10-80) | - |
| 30 - 34 | 11.5 | 59 (43-74) | 94.8 | 41.2 | 77 (10-175) | 93.2 |

(1) Based on average influent O&G of 1125 mg.L$^{-1}$

The ratio recorded between O&G and COD for the influent wastewater, effluent and sludge is provided in Table 5-7.

Table 5-7. Ratio of O&G to COD

| | Ratio of O&G to COD(1) | | | |
|---|---|---|---|---|
| | Influent Wastewater | Lagoon 1 Effluent | Lagoon 1 Sludge | Lagoon 2 Effluent |
| Mean | 0.131 | 0.052 | 0.049 | 0.055 |

(1) Average ratios based on data from Week 3 to Week 34.

## 5.6 Solids Analysis

Solids analysis has been undertaken in several forms which can provide information on various aspects of the lagoons' performance. These are as follows;

- SS removal (5.6.1),
- sludge yield (5.6.2),
- scum layer (5.6.3), and
- SS as an operational and loading parameter (5.6.4).

A detailed list of results by sampling point, including depth, lateral and axial profiling points is given in Appendix G. The TSS and VSS have been measured at a range of sites in the lagoons to provide a profile of SS throughout the lagoon.

To allow simpler analysis of the difficult to handle sludge samples, TSS and VSS analyses were substituted by TS and VS analyses for all sludge samples.

Note, for the purposes of calculations, it has been assumed that TS/VS and TSS/VSS are equivalent units. It was considered that this does not produce a significant error when dealing with sludges.

### *5.6.1 Removal of Suspended Solids*

The TSS and VSS in the influent have been measured to assess the lagoon's performance with regard to suspended solids removal. These results are shown in Table 5-8 and 5-9 for the covered and uncovered lagoons.

The influent TSS and VSS of 2,555 mg.L$^{-1}$ and 2,344 mg.L$^{-1}$ were determined as the average of all influent grab samples and it has been assumed that this average remained constant for the period of the trial. As shown in Table 5-1, these TSS and VSS values are within the typical range of values for abattoir wastewaters that have been recorded elsewhere.

Table 5-8. Suspended Solids Removal in Covered Lagoon

| Week | Lagoon 1 | | | | |
|---|---|---|---|---|---|
| | HRT (days) | Effluent TSS (mg.L$^{-1}$) | Removal (%) (1) | Effluent VSS (mg.L$^{-1}$) | Removal (%) (1) |
| 3 – 7 | 29.2 | 528 | 79.3 | 445 | 81.0 |
| 8 – 9 | 14.6 | 440 | 82.8 | 350 | 85.1 |
| 10 – 22 | 37.5 | 274 | 89.3 | 225 | 90.4 |
| 23 – 29 | 18.7 | 284 | 88.9 | 225 | 90.4 |
| 30 - 34 | 11.5 | 375 | 85.3 | 326 | 86.1 |

(1) Based on average influent TSS and VSS of 2,555 mg.L$^{-1}$ and 2,344 mg.L$^{-1}$

Table 5-9. Suspended Solids Removal in the Control Lagoon

| Week | Lagoon 2 | | | | |
|---|---|---|---|---|---|
| | HRT (days) | Effluent TSS (mg.L$^{-1}$) | Removal (%) (1) | Effluent VSS (mg.L$^{-1}$) | Removal (%) (1) |
| 3 – 7 | 29.2 | 366 | 85.7 | 290 | 87.6 |
| 8 – 9 | 12.2 | 373 | 85.4 | 295 | 87.4 |
| 10 – 22 | 42.3 | 264 | 89.7 | 212 | 91.0 |
| 23 – 29 | n/a | 199 | n/a | 131 | n/a |
| 30 – 34 | 41.2 | 294 | 88.5 | 243 | 89.6 |

(1) Based on average influent TSS and VSS of 2,555 mg.L$^{-1}$ and 2,344 mg.L$^{-1}$

### *5.6.2 Sludge Layer*

A sludge layer existed in each lagoon prior to the field scale trials commencing in March 1997. This layer evolved from seed sludge introduced in early 1996 and sedimentation of solids from wastewater which had been introduced into the lagoons during the long commissioning period. Another seeding in March 1997 and subsequent operation of the lagoons lead to further sludge layer development.

Sludge layer thickness measurements, along with total suspended solids (TSS) and volatile suspended solids (VSS) measurements, are given in Tables 5-10, 5-11 and 5-12 for the high activity zone and settling zone of lagoon 1 and lagoon 2.

Table 5-10. Sludge Layer Measurements in High Activity Zone (Lagoon 1)

| Date | Week | L1.2.6a (1) t (2) (m) | L1.2.6a (1) TS (% w/w) | L1.2.6a (1) VS (% w/w) | L1.2.6b (1) t (m) | L1.2.6b (1) TS (% w/w) | L1.2.6b (1) VS (% w/w) |
|---|---|---|---|---|---|---|---|
| 5 Sep 96 | - | 0.69 | 1.75 | - | 0.69 | 1.75 | - |
| 9 Apr 97 | 3 | - | - | - | - | 8.76 | 6.88 |
| 2 May 97 | 6 | 0.30 | 5.43 | 4.27 | 0.20 | 1.39 | 1.16 |
| 7 May 97 | 7 | 0.20 | - | - | 0.30 | - | - |
| 20 May 97 | 9 | - | 5.26 | 3.50 | - | 3.03 | 2.43 |
| 23 Jul 97 | 18 | - | 2.86 | 2.30 | - | 3.35 | 2.73 |
| 20 Aug 97 | 22 | - | 3.91 | 3.21 | - | 3.35 | 2.75 |
| 24 Sep 97 | 27 | 0.30 | - | - | - | - | - |
| 8 Oct 97 | 29 | 0.50 | 3.85 | 3.14 | 0.70 | 3.70 | 3.03 |
| 29 Oct 97 | 32 | - | 3.01 | 2.44 | - | 3.47 | 2.84 |
| 13 Nov 97 | 34 | 0.55 | - | - | 0.95 | - | - |

(1) Sample location "a" – left-hand side,
Sample location "b" – right-hand side,
(Refer to Figure 3.1).
(2) t = thickness

Table 5-11. Sludge Layer Measurements in Settling Zone (Lagoon 1)

| Date | Week | L1.3.6a (1) t (2) (m) | L1.3.6a (1) TS (% w/w) | L1.3.6a (1) VS (% w/w) | L1.3.6b (1) t (m) | L1.3.6b (1) TS (% w/w) | L1.3.6b (1) VS (% w/w) |
|---|---|---|---|---|---|---|---|
| 5 Sep 96 | - | 0.40 | 1.75 | - | 0.4 | 1.75 | - |
| 9 Apr 97 | 3 | - | - | - | - | 5.81 | 4.63 |
| 2 May 97 | 6 | 0.20 | 6.10 | 4.89 | - | 2.23 | 1.72 |
| 7 May 97 | 7 | 0.65 | - | - | 0.20 | - | - |
| 20 May 97 | 9 | - | 2.63 | 2.12 | - | 3.01 | 2.41 |
| 23 Jul 97 | 18 | - | 3.35 | 2.72 | - | 4.07 | 3.32 |
| 20 Aug 97 | 22 | - | 4.17 | 3.43 | - | 4.14 | 3.41 |
| 24 Sep 97 | 27 | 0.35 | - | - | - | - | - |
| 8 Oct 97 | 29 | 0.45 | 2.55 | 2.05 | 0.60 | 2.68 | 2.12 |
| 29 Oct 97 | 32 | - | 0.49(3) | 0.39(3) | - | 3.22 | 2.64 |
| 13 Nov 97 | 34 | 0.45 | - | - | 0.55 | - | - |

(1) Sample location "a" – left-hand side,
Sample location "b" – right-hand side,
(Refer to Figure 3.1).
(2) t = thickness
(3) Week 34 results appear to have been influenced by the '"bubble" and resultant interference on the baffle.

Table 5-12 Sludge Layer Measurements in Uncovered Lagoon (Lagoon 2)

| Date | Week | L2.2.6a [1] | | L2.2.6b [1] | | | L2.2.6c [1] | |
|---|---|---|---|---|---|---|---|---|
| | | TS (% w/w) | VS (% w/w) | t [2] (m) | TS (% w/w) | VS (% w/w) | TS (% w/w) | VS (% w/w) |
| 5 Sep 96 | - | - | - | 0.67 | 1.87 | - | - | - |
| 2 May 97 | 6 | 4.07 | 2.98 | 1.20 | 4.83 | 3.55 | 4.33 | 3.08 |
| 7 May 97 | 7 | - | - | - | - | - | - | - |
| 20 May 97 | 9 | 3.79 | 2.78 | | 3.98 | 2.93 | 4.58 | 3.39 |
| 23 Jul 97 | 18 | - | - | - | 5.59 | 4.15 | - | - |
| 20 Aug 97 | 22 | - | - | | 3.50 | 2.66 | - | - |
| 24 Sep 97 | 27 | - | - | 1.20 | - | - | - | - |
| 8 Oct 97 | 29 | - | - | - | 5.16 | 3.84 | - | - |
| 13 Nov 97 | 34 | - | - | - | - | - | - | - |

(1) Sample location "a" – inlet end,
Sample location "b" – centre,
Sample location "c" – outlet end,
(Refer to Figure 3.1).

(2) t = thickness

From these sludge layer measurements an estimate of sludge yield has been calculated. These are presented in Table 5-13.

Table 5-13. Sludge Yield

| | Lagoon 1 (kgVSS.kgCOD$^{-1}$) | Lagoon 2 (kgVSS.kgCOD$^{-1}$) |
|---|---|---|
| Week 6 to 29 | 0.0099 | 0.1160 |
| Week 30 to 34 | 0.0047 | No data |
| Week 6 to 34 | 0.0082 | No data |

Units: kgVSS yielded per kg COD removed.

### *5.6.3 Scum Layer*

The measurement of the scum layer was largely subjective with records of lagoon coverage and scum description being made periodically. These, along with a measurement of the scum thickness are recorded in Table 5-14 and Table 5-15 for the covered and uncovered lagoons, respectively.

Two samples of the scum layer in the covered lagoon were taken on 2 December 97 for O&G analysis giving 10,000 and 42,500 mg.L$^{-1}$. These samples corresponded to a "spongy cake" description, as per Tables 5-14 and 5-15.

Taking an average of the scum thickness from Weeks 27 to 32 to calculate scum volume and applying the above O&G values to this volume, the total amount of O&G in the scum layer can be estimated as;

<u>Lagoon 1</u>

| | | | |
|---|---|---|---|
| Zone 1 | = | 1,133 – 4,815 | kg |
| Zone 2 | = | 585 – 2,486 | kg |
| Total | = | 1,718 – 7,301 | kg |

<u>Lagoon 2</u>

| | | | |
|---|---|---|---|
| Total | = | 2,352 – 9,996 | kg |

Table 5-14. Scum Records for the Covered Lagoon (Lagoon 1)

| DATE | Week | L1.2.a t [1] (mm) | L1.2.a Description | L1.2.b t (mm) | L1.2.b Description | L1.3.a t (mm) | L1.3.a Description | L1.3.b t (mm) | L1.3.b Description | L1.3.c t (mm) | L1.3.c Description | L1.3.d t (mm) | L1.3.d Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30-Apr-97 | 6 | 100 | mousse | 100 | mousse | 150 | mousse | 150 | mousse | 0 | none | 2 | slime |
| 20-May-97 | 9 | 150 | - | 150 | - | 150 | - | 150 | - | - | - | - | - |
| 28-Jul-97 | 19 | 125 | dry mousse | 150 | dry mousse | 175 | dry mousse | 150 | mousse | 0 | none | 0 | none |
| 24-Sep-97 | 27 | 250 | solid cake | 250 | solid cake | 175 | weak cake | 175 | weak cake | 0 | none | 0 | none |
| 8-Oct-97 | 29 | 100 | weak cake | 200 | cake | 200 | cake | 200 | cake | 5 | slime | 100 | cake |
| 29-Oct-97 | 32 | 250 | sponge cake | 250 | sponge cake grey powder | 200 | cake | 200 | cake | 5 - 50 | slime - sponge | 75 | sponge |
| 13-Nov-97 | 34 | 0 | none | 200 | sponge cake grey powder | 125 | moist cake | 125 | moist cake | 0 | none | 0 | none |

(1) t = thickness of scum layer

(2) Location Codes – for a graphical representation of the all the sampling locations refer to Figure 4-1, p.36.

*eg.* L1.2.a

Lagoon no.
1-covered
2-uncovered

Zone of sampling

Sampling point within the zone

Table 5-15. Scum Records for the Uncovered Lagoon (Lagoon 2)

| DATE | Week | Location L2.2.a | | L2.2.b | | L2.2.c | |
|---|---|---|---|---|---|---|---|
| | | t [1] (mm) | Description | t (mm) | Description | t (mm) | Description |
| 30-Apr-97 | 6 | 100 | mouse | 100 | mouse | 150 | mouse |
| 20-May-97 | 9 | 150 | | 150 | | 150 | |
| 28-Jul-97 | 19 | 125 | dry mouse | 150 | dry mouse | 175 | dry mouse |
| 24-Sep-97 | 27 | 250 | solid cake | 250 | solid cake | 175 | weak cake |
| 8-Oct-97 | 29 | 100 | weak cake | 200 | cake | 200 | cake |
| 29-Oct-97 | 32 | 250 | sponge cake | 250 | sponge cake grey powder | 200 | cake |
| 13-Nov-97 | 34 | 0 | none | 200 | spongey cake /grey powder | 125 | moist cake |

(1) t = thickness of scum layer

### *5.6.4 Mixed Liquor Volatile Suspended Solids*

As an operating parameter in aerobic systems, suspended solids are commonly considered in the form of MLVSS. This parameter aims to provide a general indication of the amount of active biomass in a treatment reactor. It is becoming more popular to also consider such a parameter in anaerobic systems.

In simple anaerobic lagoons such asin this project, the MLVSS is calculated knowing the VSS of the sludge and bulk liquid and the volume of each. For the purposes of these calculations the bulk liquid VSS has been taken as that recorded at a depth of 3m (see Appendix G).

The trials commenced with a MLVSS content of approximately 1,000 mg.L$^{-1}$ in each lagoon (Table 4-6). The development of this MLVSS over the 34 week trial period is summarised in Table 5-16.

Table 5-16. Operating Mixed Liquor Volatile Suspended Solids (MLVSS)

| Week | Lagoon 1 Zone 1 (mg.L$^{-1}$) | Zone 2 (mg.L$^{-1}$) | Combined (mg.L$^{-1}$) | Lagoon 2 (mg.L$^{-1}$) |
|---|---|---|---|---|
| 0 | n/a | n/a | 252 | 333 |
| 3 | no data | no data | 998 [1] | 1033 [1] |
| 6 | 691 | 641 | 658 | 2,323 |
| 29 | 856 | 584 | 675 | 2,383 |
| 34 | 1,378 | 842 | 1,020 | no data |

(1) Based on VSS supplied by inoculum sources during seeding.

### 5.6.5 *Correlation of Suspended Solids*

Table 5-17 shows the ratio of TSS and VSS with each other and COD.

Table 5-17. Ratios of Suspended Solids

| Ratio | Influent Wastewater | Lagoon 1 | | Lagoon 2 |
|---|---|---|---|---|
| | | Effluent O&G | Sludge O&G | Effluent O&G |
| VSS/TSS | 0.91 | 0.83 | 0.81 | 0.78 |
| TSS/COD | 0.35 | 0.34 | 0.95 | 0.32 |
| VSS/COD | 0.32 | 0.28 | 0.78 | 0.24 |

(1) Average ratios based on data from Week 3 to Week 34.

## 5.7 Nutrients

The nutrients targeted for analysis have been nitrogen and phosphorous in the form of ammonium ($NH_4^+$-N), nitrate/nitrite (NOx), total nitrogen (Total N) and total phosphorous (Total P). A detailed list of results for each parameter by sampling point (including depth, lateral and axial profiling points) is given in Appendix G. These results, measured at a range of sites in the lagoons, provide a profile of the nutrients throughout the lagoon.

Summaries of influent and effluent concentrations of $NH_4$-N, Total N and Total P are provided in the following tables (5-18, 5-19 & 5-20). NOx values, although measured, were generally below detection limits (<0.05 $mg.L^{-1}$) and consequently are not presented here.

Table 5-18 Effluent Ammonia ($NH_4^+$-N)

| Week | Wastewater Influent ($mg.L^{-1}$) | Covered Lagoon Effluent ($mg.L^{-1}$) | Control Lagoon Effluent ($mg.L^{-1}$) |
|---|---|---|---|
| 3 – 7 | 55 | 117 | 115 |
| 8 – 9 | " | 155 | 138 |
| 10 – 22 | " | 108 | 114 |
| 23 – 29 | " | 121 | 106 |
| 30 – 34 | " | 129 | 149 |

Table 5-19. Effluent Total Nitrogen

| Week | Wastewater Influent ($mg.L^{-1}$) | Covered Lagoon Effluent ($mg.L^{-1}$) | Control Lagoon Effluent ($mg.L^{-1}$) |
|---|---|---|---|
| 3 – 7 | 280 | 268 | 234 |
| 8 – 9 | " | 255 | 245 |
| 10 – 22 | " | 218 | 212 |
| 23 – 29 | " | 226 | 225 |
| 30 – 34 | " | 256 | 238 |

Table 5-20. Effluent Phosphorous (as Total P)

| Week | Wastewater Influent ($mg.L^{-1}$) | Covered Lagoon Effluent ($mg.L^{-1}$) | Control Lagoon Effluent ($mg.L^{-1}$) |
|---|---|---|---|
| 3 – 7 | 38.6 | 31.0 | 30.0 |
| 8 – 9 | " | 32.0 | 34.0 |
| 10 – 22 | " | 28.7 | 26.7 |
| 23 – 29 | " | 29.0 | 27.5 |
| 30 – 34 | " | 31.3 | 32.1 |

Table 5-21. Concentration of Nutrients in Recycled Sludge of Lagoon 1

| Week | Total Nitrogen ($mg.L^{-1}$) | Ammonia ($mg.L^{-1}$) | Phosphorous ($mg.L^{-1}$) |
|---|---|---|---|
| 3 – 7 | no data | 160 | no data |
| 8 – 9 | 1235 | 173 | 150 |
| 10 – 22 | 1786 | 148 | 190 |
| 23 – 29 | 1731 | 185 | 180 |
| 30 – 34 | 1958 | 258 | 170 |

## 5.8 Temperature

Temperature in the lagoons has been recorded on an hourly basis using data loggers at two locations in the covered lagoon and one location in the control lagoon. Figure 5-3 shows the trend of temperature in the Lagoon 1 and Figure 5-3 shows the trend of temperature in the Lagoon 2. The influent temperature has also been recorded on a weekly basis as part of Southern Meats' normal monitoring program and monthly averages are illustrated in the two Figures 5-3 & 5-4.

## 5.9 Odour

No measurements have been taken on-site to date. No methodology for measuring the reduction in odour as a result of the cover has been developed. Background levels of odour from other nearby sources such as the existing anaerobic lagoon, control lagoon and other abattoir processes will all mask the effect of the cover to reduce odour from the one lagoon.

**Figure 5.3**

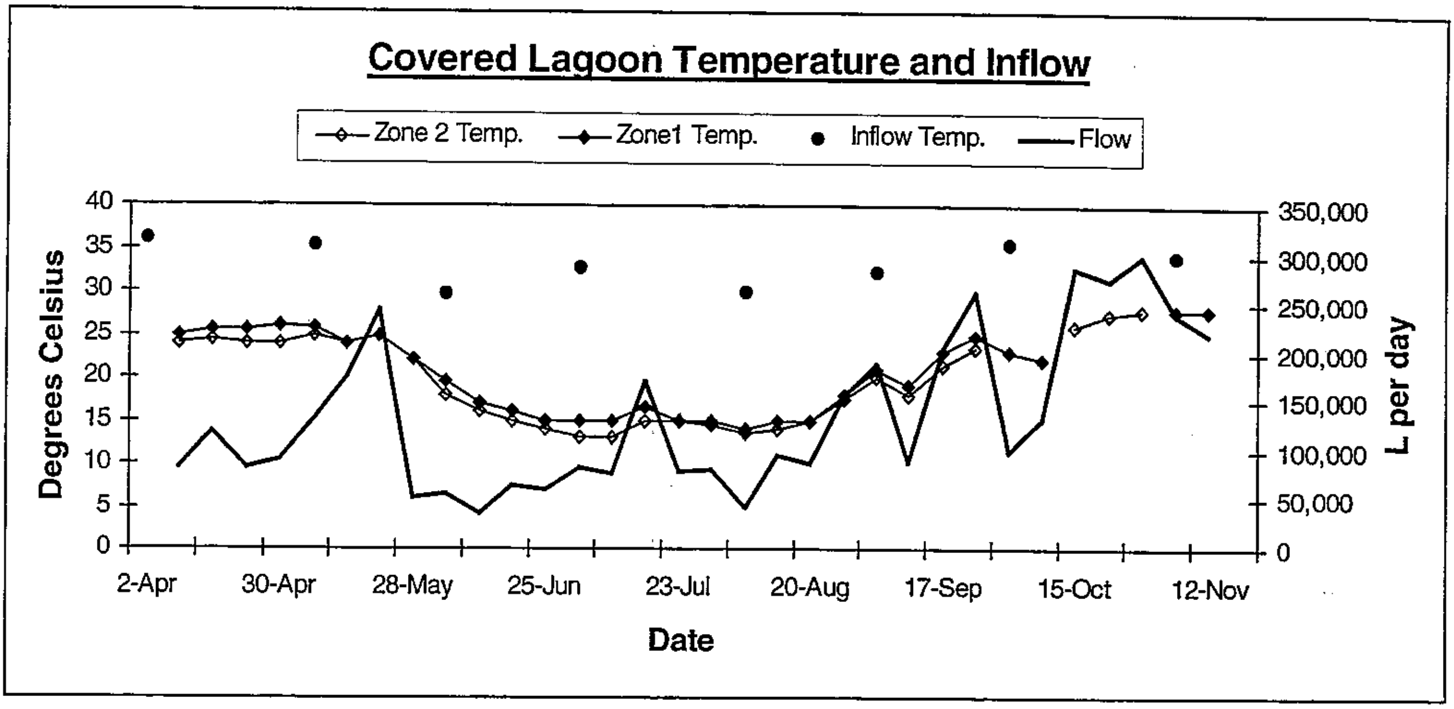
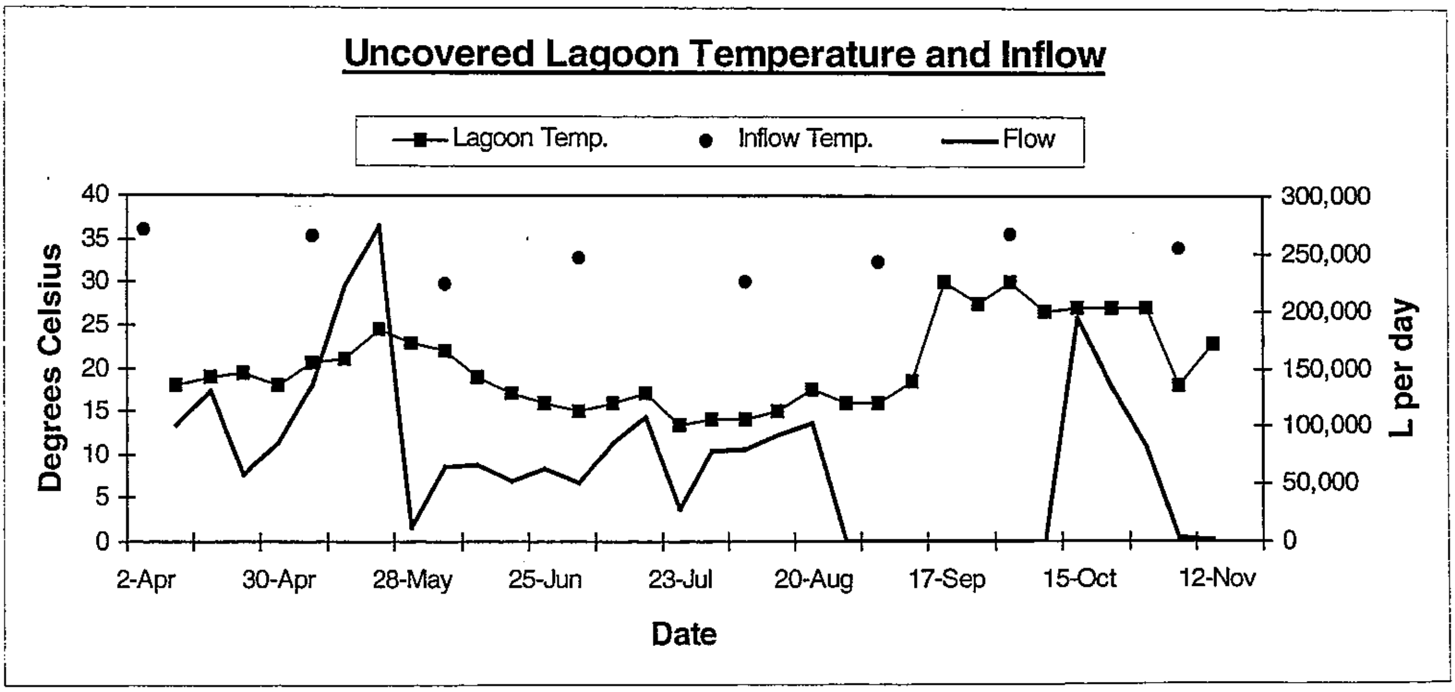



**Figure 5.4**



# 6. DISCUSSION OF RESULTS

## 6.1 Biomass Development and Acclimation

As indicated in Section 4.3.1, initial seeding (1996) aimed to achieve a desired MLVSS of 5,000 $mg.L^{-1}$ in each lagoon. Due to the delays in construction and commissioning, however, a second seeding (1997) was required which, due to project budget constraints, could only achieve a MLVSS of 1,000 $mg.L^{-1}$.

For the Covered Lagoon, Table 5-16 shows a drop in the level of the biomass (as MLVSS) after the initial seeding (Week 1- 3) before slowly regaining the level of 1,000 $mg.L^{-1}$ during the Week 30 to 34 period. This can be explained by the die-off of the non-acclimatised bacteria coming from the Goulburn STP digesters. Only a small fraction of the bacteria from the STP digesters is expected to acclimatise to the different organic substrate of abattoir wastewater. The low and interrupted supply of organic substrate (Figure 5-1) due to commissioning and operating difficulties further hampered the development and acclimatisation of a satisfactory biomass.

From the projected growth[2], however, it could be expected that by 10th March 1998 (expected date for continuation of trials) the covered lagoon should have the following MLVSS levels;

| | Zone 1 | Zone 2 | Combined | |
|---|---|---|---|---|
| MLVSS | 3,153 | 1,719 | 2,197 | $mg.L^{-1}$ |

This development could be expected as a minimum, given that the higher OLR during this period to date, and the higher ambient temperature of summer, will have helped support a higher biomass development. These aspects will be monitored and reported on further in the report of the trial's continuation in 1998.

MLVSS data for the uncovered lagoon was not measured as rigorously as for the covered lagoon (only one location measured) resulting in an unexpectedly high estimate of the MLVSS in the lagoon. It is expected that the MLVSS should be equal, if not less, than the covered lagoon due to the generally lower feed and at times non-existent feed supplied to the uncovered lagoon.

It is recommended that MLVSS data from the uncovered lagoon be rigorously measured prior to commencement of the project extension to allow a more accurate estimate of the MLVSS. The CRC/CWWT is currently awaiting the repair and return of the SS meter which was being used for this analysis.

Returning to the covered lagoon data in Table 5-16, it can be seen that Zone 1 consistently had a higher level of MLVSS and that the biomass development in this Zone was greater than in Zone 2. This provides evidence indicating that a high activity zone is being created in the first zone and supports the effectiveness of the baffle[3].

The Laboratory Studies indicated a MLVSS of 2,100 to 4,500 $mg.L^{-1}$ was desirable at start-up and by the completion of the laboratory studies

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[2] Based on the MLVSS development from Week 29 to 34.

[3] See discussion on "bubble" and implications for baffle performance in Section 4.3.5 & Appendix H.

operational MLVSS of the reactors was of the order of 10,000 $mg.L^{-1}$ (see Table 6-1). By comparison the field scale lagoons were not given the same start and as yet the operational MLVSS has not built up to such desirable levels as achieved in the laboratory reactors. The attainment of satisfactory MLVSS levels, however, are anticipated prior to continuation of trials, as mentioned above.

Table 6-1. Summary of Operating MLVSS for Laboratory Reactors

| Week | Zone 1 ($mg.L^{-1}$) | Zone 2 ($mg.L^{-1}$) | Combined ($mg.L^{-1}$) |
|---|---|---|---|
| **Reactor 2 – Fixed Film** | | | |
| 0 (1st start) | n/a | n/a | > 2,700 (1) |
| 30 (2nd (start) | 20,678 | 900 | 7,493 (2) |
| 59 (end) | 14,977 | 8,123 | 10,408 (2) |
| **Reactor 3 – Contact Process** | | | |
| 0 (1st start) | n/a | n/a | 2,700 |
| 30 (2nd start) | 4,500 | 900 | 2,100 |
| 58 (end) | 10,944 | 8,583 | 9,370 |

(1) Reactor 2 was started with the same amount of seed sludge as Reactor 3 plus pre-seeded fixed films. Hence, this additional biomass would increase the starting MLVSS compared to Reactor 3, but actual data is not available.

(2) Combined MLVSS includes estimate of VSS in fixed film.

## 6.2 Fate of Organic Carbon

Despite the low biomass development and interrupted loading, both lagoons showed satisfactory removal of COD (Table 5-4). The removal was generally above 80% resulting in an effluent COD of below 1,000 $mg.L^{-1}$ from an estimated average influent COD of 6,000 $mg.L^{-1}$. Given the low OLR applied, these results are to be expected, but show that the lagoons have started satisfactorily.

It is generally accepted that the organic carbon will end up in one of four areas;

- effluent,
- biogas,
- scum, or
- sludge.

To determine the exact mass balance for organic carbon has been difficult. The effluent and sludge components have been fairly accurately measured but measurement of the biogas component, which should also be easily measured, has not been possible to date due to faulty equipment[4]. Finally, the scum component, particularly in the covered lagoon, remains largely a guesstimate due to the broad measurement/estimate of scum volume present on the lagoons.

[4] This has now been rectified by the sub-contractor for the continuation of trials in 1998.

Figure 6-1 (a) provides an approximate mass balance of organic carbon (as COD) for the covered lagoon. This mass balance was based on the measurement of influent, effluent, sludge and scum[5] COD levels with the COD value of biogas assumed to make up the difference. This could not be confirmed by measurement due to the unreliable operation of the biogas flow meter. However, the mass balance leads to an implied biogas production rate of ~ 0.271 $m^3CH_4.kgCOD_R^{-1}$ which is similar to the 0.235 $m^3CH_4.kgCOD_R^{-1}$ demonstrated in the laboratory studies and supports results given in the mass balance to within "ball park" accuracy.

The same has been done for the uncovered lagoon in Figure 6-1 (b), although this is based on unreliable sludge data and so results are not as accurate.

Comparison of data from Tables 5-7 and 5-17 shows the changing composition of the COD. Whereas in the influent wastewater O&G is a significant contributor to the COD, in the effluent the contribution is significantly reduced while the relative contribution from SS is increased.

## 6.3 Fate of Oil & Grease

The removal of O&G by the two lagoons has been good with an average of 94.7% and 92.8% from Lagoon 1 and Lagoon 2 respectively, being achieved with hydraulic retention times as low as 11.5 days (Table 5-6). This removal resulted in a low average effluent O&G concentration of 60.7 $mg.L^{-1}$ and 81.5 $mg.L^{-1}$ for Lagoon 1 and Lagoon 2, respectively. The fate of the oil and grease in the wastewater is illustrated in the mass balance shown in Figure 6-2 for the covered and uncovered lagoons. This mass balance of O&G is for the period from Week 3 to Week 34.

For the covered lagoon, the mass balance shows that of the 94.7% of O&G removed (on average), 25.9% accumulated in the scum layer, 0.4% accumulated in the sludge layer and the remaining 68.4% was removed via non-accounted means, most likely by conversion to $CH_4/CO_2$ in the biogas and some volatilisation. For the uncovered lagoon, the mass balance shows that of the 92.8% of O&G removed (on average), 41.4% accumulated in the scum layer, 2.5% accumulated in the sludge layer and the remaining 56.1% was removed via non-accounted means. These results suggest an accumulation of O&G over time in the scum layer which is a significant contributor to O&G removal from the wastewater.

The generation of a scum layer has two main implications. Firstly, it acts as an insulating cover which improves heat retention and reduces transfer of oxygen to the anaerobic lagoon. It was hoped that the ability, or inability, of a scum layer to maintain temperature could be ascertained on the uncovered lagoon during these trials. A result has not been established to date, however, due to the fluctuating flow to the uncovered lagoon which led to the coming and going of the scum layer.

Secondly, and less favourably, scum accumulation means a reduction in the effective volume of the lagoon will occur over time.

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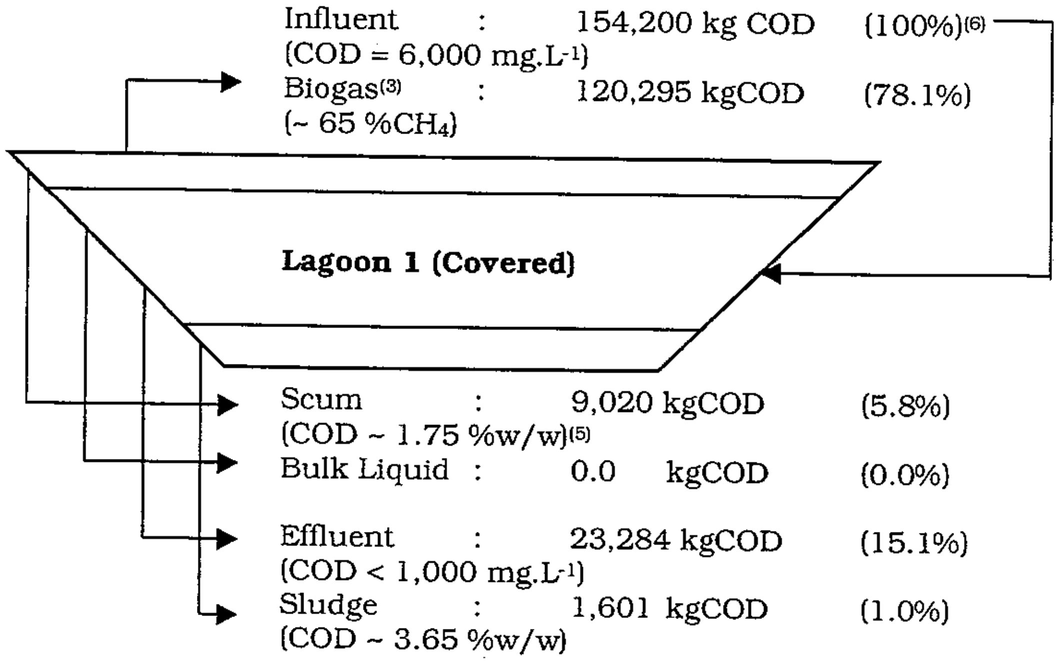
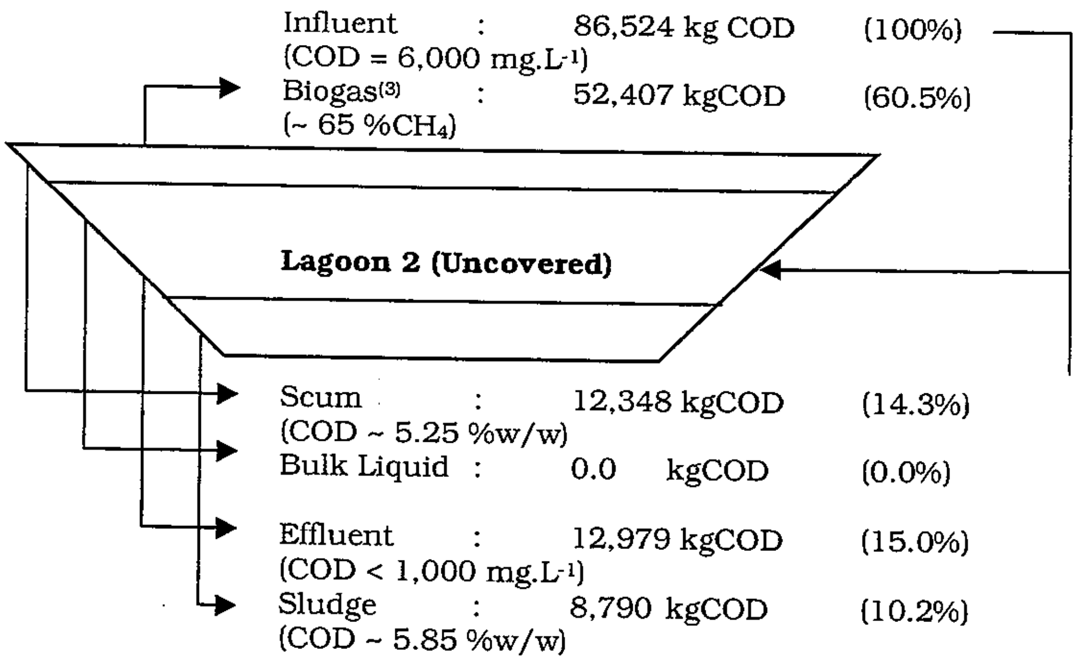
[5] COD of scum calculated from O&G measurement and assumed ratio of COD:O&G of 1:3.

**Figure 6-1.**

(a) Mass Balance(1) of Organic Matter (as COD) for the Covered Lagoon




(b) Mass Balance(1) of Organic Matter (as COD) for the Uncovered Lagoon

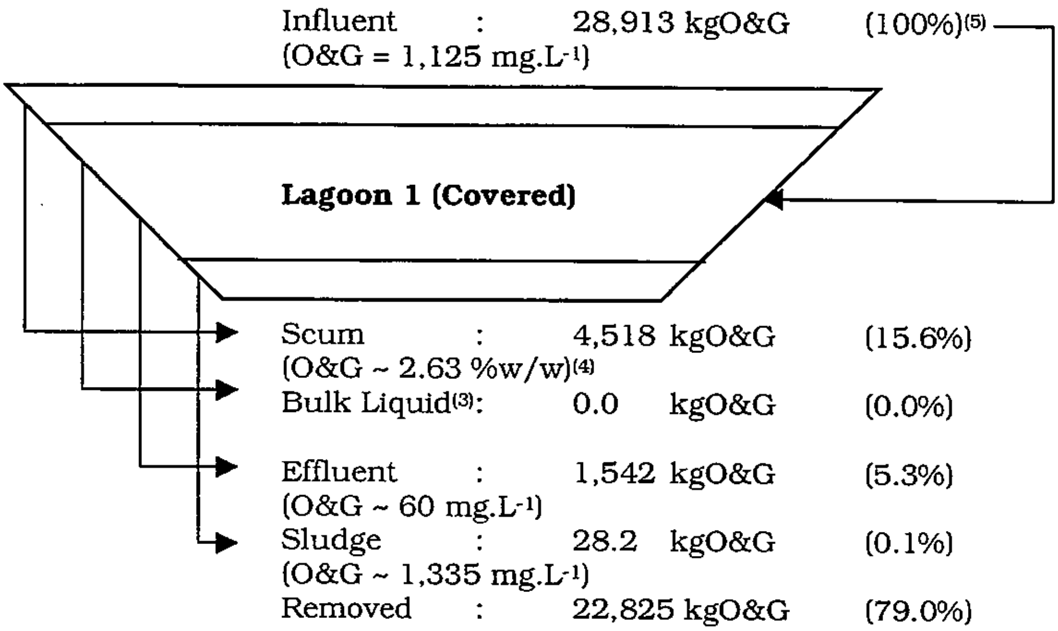



Notes:

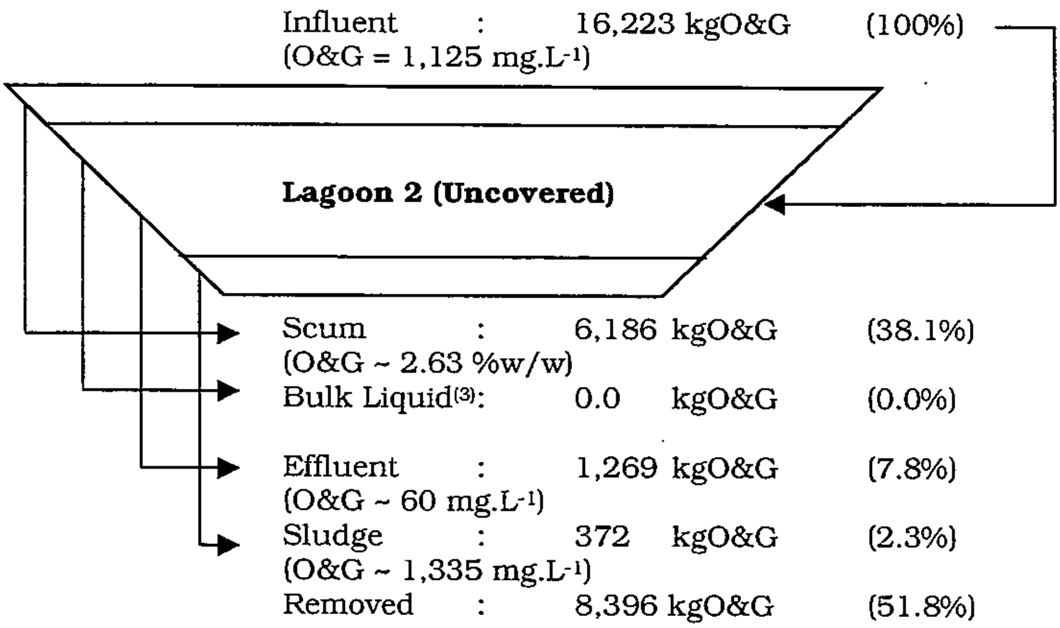
(1) Calculations based on data from Week 3 to Week 34 where OLR ranged from to 0.16 to 0.52 $kgCOD.m^{-3}.d^{-1}$.
(2) Influent, effluent, sludge and scum COD based on measured data.
(3) Biogas COD based on balance of COD from above parameters.
(4) Bulk liquid storage of COD assumed zero.
(5) %w/w assumed equal to $mg.L^{-1}$.
(6) % figures in brackets represent % of applied COD.

**Figure 6-2.**

(a) Mass Balance(1) of O&G for the Covered Lagoon




(b) Mass Balance(1) of O&G for the Uncovered Lagoon




Notes:

(1) Based on data from Week 3 to Week 34 where OLR ranged from to 0.16 to 0.52 $kgCOD.m^{-3}.d^{-1}$.
(2) Influent, effluent, sludge and scum O&G based on measured data.
(3) Bulk liquid storage of O&G assumed zero.
(4) %w/w assumed equal to $mg.L^{-1}$.
(5) % figures in brackets represent % of applied O&G.

These results are based on the assumption that the scum layer developed from nothing (as it was at the start of the trials) to its present average thickness. The scum layer measurements (Table 5-14 & 5-15), however, suggest that an equilibrium has been reached and that no further growth (or very little) is occurring as biomass activity develops in each lagoon and the scum layer becomes a source of organic substrate.

The fact that the scum layer did come and go with fluctuating flow to the uncovered lagoon suggests an easy degradability of the scum layer. Further, the thickness of the scum layer in the covered lagoon also fluctuated, which suggests a possible equilibrium being reached. The upgrading of the lagoons for further trials will ensure a regular flow and allow better assessment of this issue. The scum layer also seemed reach a steady state in the lab reactor.

## 6.4 Removal of Suspended Solids

The performance of the two lagoons for suspended solids removal has been good with 80-90% removal consistently being achieved (Table 5-8 & 5-9) at hydraulic retention times as low as 11.5 days.

Solids accumulation is one of the main factors which determine the life of an anaerobic lagoon leading to the reduction of the effective volume of the lagoon to the point where satisfactory hydraulic retention times can not be achieved for the desired flow rate. The overall rate of solids accumulation (sludge yield) measured from Week 6 to 34 was 0.0082 $kgVSS.kgCOD_R^{-1}$ and 0.116 $kgVSS.kgCOD_R^{-1}$ in the covered and uncoverd lagoons, respectively (Table 5-13).

The very low rate of sludge accumulation in the covered lagoon compares favourably with rates measured in the laboratory studies (0.077 $kgVSS.kgCOD_R^{-1}$) and other research (0.02 to 0.03 $kgVSS.kgCOD_R^{-1}$). The sludge yield in the uncovered lagoon is unfavourably high, but this figure is based on limited data and is considered unreliable.

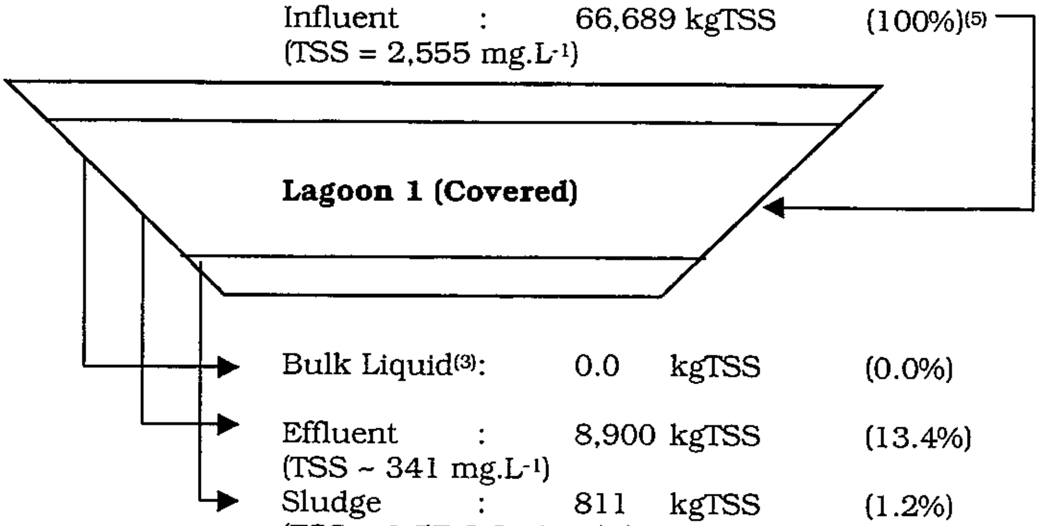
A mass balance of total suspended solids has been prepared for each lagoon and this is shown in Figure 6-3. Only influent, effluent and sludge TSS is considered in these mass balance calculations. The TSS of the scum layer has not been measured due to the difficulty in obtaining a representative sample, or the large number of samples required to obtain an accurate average.

Note also, that for the uncovered lagoon the small number of sludge samples makes its mass balance calculation unreliable.

**Figure 6-3**

(a) Mass Balance[1] of TSS for the Covered Lagoon

Influent : 66,689 kgTSS (100%)[5]
(TSS = 2,555 mg.L$^{-1}$)




Bulk Liquid[3]: 0.0 kgTSS (0.0%)

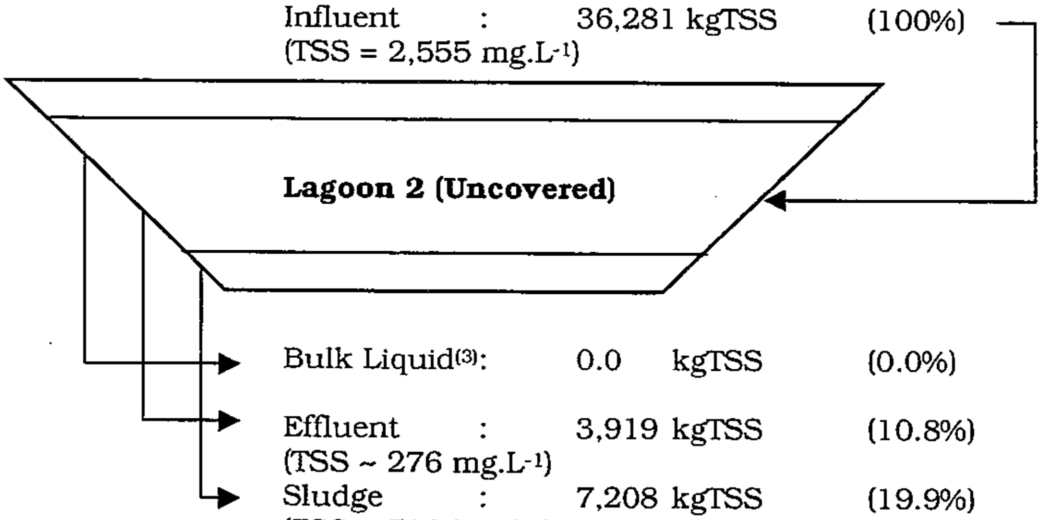
Effluent : 8,900 kgTSS (13.4%)
(TSS ~ 341 mg.L$^{-1}$)

Sludge : 811 kgTSS (1.2%)
(TSS ~ 1.57-3.24 %w/w)[4]

Removed[6] : 56,978 kgTSS (85.4%)

(b) Mass Balance[1] of TSS for the Uncovered Lagoon

Influent : 36,281 kgTSS (100%)
(TSS = 2,555 mg.L$^{-1}$)




Bulk Liquid[3]: 0.0 kgTSS (0.0%)

Effluent : 3,919 kgTSS (10.8%)
(TSS ~ 276 mg.L$^{-1}$)

Sludge : 7,208 kgTSS (19.9%)
(TSS ~ 516 %w/w)

Removed[6] : 25,154 kgTSS (69.3%)

Notes:

(1) Based on data from Week 3 to Week 34 where OLR ranged from to 0.16 to 0.52 kgCOD.m$^{-3}$.d$^{-1}$.
(2) Influent, effluent and sludge TSS based on measured data.
(3) Bulk liquid storage of TSS assumed zero.
(4) %w/w assumed equal to mg.L$^{-1}$.
(5) % figures in brackets represent % of applied TSS.
(6) "Removed" includes TSS in scum. Not measured.

## 6.5 Fate of Nutrients

### 6.5.1 Nitrogen

As expected very little nitrate/nitrite (0.03 mg.$L^{-1}$) was evident in the incoming wastewater (Table 5-1) while ammonia represented only 55 mg.$L^{-1}$ of the 280 mg.$L^{-1}$ of total nitrogen. Consequently, it can be concluded that 80% (225 mg.$L^{-1}$) of the total nitrogen in the wastewater is in an organic form.

Table 5-19 indicates that the total nitrogen in the effluent is reduced by a small degree (up to 20% reduction), however the average concentration of Total N (234 & 224 mg.$L^{-1}$ for Lagoon 1 & 2 respectively) is still a significantly high value.

While anaerobic denitrification may account for some N loss as $N_2$ gas, sedimentation and accumulation in the sludge (Table 5-21) are the most likely paths for the N loss. Table 5-21 indicates that the majority of the N in the sludge is organic N.

From Table 5-18 it is evident that some of the organic N undergoes ammonification resulting in the concentration of ammonia in the effluent of the lagoons rising to an average of 118 & 119 mg.$L^{-1}$ for Lagoon 1 & 2, respectively (~50% of Total N). The organic N contribution to Total N in the effluent is reduced to around 50%.

The conversion of organic N to ammonium is a favourable process as N in the ammonium form is more easily oxidised to nitrite/nitrate in the following aerobic treatment stages. This assists the biological nutrient removal (BNR) of nitrogen in the aerobic stages.

### 6.5.2 Phosphorous

The average level of Phosphorous in the wastewater was 38.6 mg.$L^{-1}$ which was reduced slightly to an average of 29.7 & 28.6 mg.$L^{-1}$ in the effluent of the covered and uncovered lagoons, respectively (Table 5-20). The removal could be attributed to sedimentation and accumulation of Phosphorous in the sludge (Table 5-21).

## 6.6 Biogas and Odours

As discussed Section 6.2 (Fate of Organic Carbon) a significant amount of the carbon removed is converted to carbon dioxide and methane in the biogas. This represents a valuable energy source and its utilisation has potential benefits (Section 8).

Other constituents of the gas were not measured during this project, but it is expected that $H_2S$ would form a significant contribution. A more detailed investigation of the biogas's constituents would be required to allow a more comprehensive assessment of the potential for biogas utilisation.

Odours have not been measured on site due to the difficulty in isolating the source of odours from the covered lagoon versus to the two uncovered lagoons nearby and the general background of odours emanating from the abattoir.

It can be noted that the lagoon is fully sealed with the only potential source of odours being the exhaust gasses of the flare. This may be significant, however, as $H_2S$ is not greatly reduced by flaring. Use of the biogas in the boilers would likely result in the need to scrub the gas for $H_2S$ removal and so the odour potential would be lessened. These details need to be addressed when the lagoon is fully operational in 1998.

## 6.7 Temperature

Due to the fluctuating flows, no conclusions can be drawn on the impact of temperature on the treatment process. As shown in Figure 5-3 & 5-4, the trend in temperature largely followed the ambient temperature, dropping during winter and rising in the summer. It is hoped that once full flows become established the covered lagoon will be able to maintain a more elevated and constant temperature. It is expected that this is one of the aspects giving the covered lagoon technology an advantage over the simple uncovered lagoon. This will be investigated further in the continuation of the project in 1998.

## 6.8 Pilot Scale Reactor

Continual operation of the pilot plant was not established for periods long enough to provide meaningful data. This will be pursued in the project's continuation.

# 7. ASSESSMENT OF DESIGN AND OPERATIONS

## 7.1 Feasibility of Concept Design

The concept design for the covered lagoon was based on the two zone, contact process reactor demonstrated in the Laboratory Studies. The results to date have shown this concept to be working satisfactorily at nominal loadings. The high loadings achieved in the laboratory, however, have not yet been applied at the field scale.

Based on the results to date (namely the higher SS concentration found in the high activity zone, Section 5.6.4) it can be concluded that the baffle is effective in achieving a degree of biomass retainment in Zone 1. The baffle's effectiveness has been reduced significantly, however, since its partial flotation to the surface of the lagoon and the subsequent formation of a bubble immediately under the cover (Section 4.3.5 and Appendix H).

Sludge recycle, aimed at improving contact or mixing of biomass and organic substrate, has not been demonstrated at the field scale to date and so no conclusion can be drawn on the need to include this in future design.

Substantial biogas generation has been experienced and the flare has been operating successfully to dispose of the gas rather than venting it directly to atmosphere. This benefit of flaring is two fold. Firstly, it reduces the odour potential of the biogas and, secondly, it dramatically reduces the biogas's contribution to the greenhouse effect by converting the methane to carbon dioxide.

The potential for utilising the biogas in steam or power generation has not been demonstrated by this project. Section 8.3, however, provides a brief cost/benefit analysis of this potential based on predicted biogas generation and current natural gas usage by Southern Meats.

## 7.2 Operational Aspects

### *7.2.1 Engineering and Hydraulics*

The field lagoons have been operating to various capacities for the past two years (1996/97). During this time operational experience has been gained on which the following recommendations and guidelines are made with regard to engineering design;

(1) The nature of abattoir wastewater, with a high level of fats, grease and gross solids (wool, horns, hoofs, rags, cans, etc...) makes handling and distribution a difficult task. Pipeline design and flow control should take this into consideration, particularly up stream of pre-treatment operations such as screens or DAF.

(2) It is strongly recommended that pre-treatment screens should be applied to the raw wastewater to remove all gross solids. Preliminary removal of O&G for tallow recovery and reduction of load to anaerobic lagoons is also strongly recommended.

In the case of Southern Meats it was found that not all wastewater was passed through the screens and consequently flow to the anaerobic lagoons retained a high level of gross solids creating many problems in the distribution pipework.

The removal of oil & grease at Southern Meats by DAF is satisfactory and provides an economic recovery of tallow. Further upgrading of oil & grease removal, however, is recommended and would benefit downstream treatment processes.

(3) Flow distribution and control became a major issue at the trial lagoons due to the high solids. The original design with break tank, small diameter pipe, inappropriate valves (ball valves) and elaborate pipework was unsuccessful in handling the solids and providing the required flow. A better designed break tank, larger pipes, gate valves and simpler pipework have been included in the upgrading works to be completed prior to continuation of Stage 2 of the trials (see Appendix B).

The inlet header concept of many small openings across the lagoon (see Drawing H0227/000-3, Appendix E) proved to be undesirable due to blocking. On several occasions the inlet header was disconnected and cleared by rodding. A range of materials were revealed to be creating the blockages including coke cans and horns, but the bulk of the offending material seemed to be a general build up of fats and greases. It is consequently recommended that an end-of-pipe discharge be used to avoid the blockages encountered with an inlet header consisting of many small openings.

(4) The design daily hydraulic capacity of the trial lagoons must be based on the total daily flow. The inflow must be capable, however, of taking much more than this in instantaneous flow due to the fact that the abattoir generates most of its daily flow over a period very much less than 24 hours. The effluent pumps, on the other hand, can and should, be designed to remove the required flow over a 24 hour period.

In the case of these trial lagoons, the influent pipework has not been able to handle the maximum flow required and the effluent pumps require upgrading to cope with the total daily flow expected at the high OLR which will be trialed. These issues have been addressed in the upgrading works being carried out prior to Stage 2 (Appendix B).

(5) The major flaw experienced with the sludge recycle installed on the covered trial lagoon was its inability to remain primed and subsequent inability to prime itself. This meant the sludge recycle pump could not be operated automatically. This issues has been addressed in the upgrading works being carried out prior to Stage 2 (Appendix B).

(6) The biogas flare operates on the pressure of biogas in the lagoon cover. The flare will start at a designated high pressure (1.0 mm $H_2O$) and shut down at a designated low pressure (-3.0 mm $H_2O$). A controller and associated valve are used to operate at a given pressure set point (-1.0 mm $H_2O$) with the aim of matching the flaring rate with the biogas production rate.

The biogas flare has suffered from a range of operational problems. The most significant is its susceptibility to high winds, which occurs in two ways. Firstly, at start-up the flame can be extinguished resulting in the flare cycling through its start-up procedure indefinitely. High winds do not seem a problem when the flare has been operating for an extended period. Secondly, high winds can create fluctuations in the cover pressure beyond the normal operating range (-3.0 to 1.0 mm $H_2O$) resulting in undesirable on-off cycling of the flare. This issue requires further investigation during Stage 2 to consider possible remedial actions.

In addition to the above, the flare has also suffered minor faults relating to installation workmanship (loose wires etc...).

It is because of these issues that accurate monitoring of biogas production has not been possible to date.

(7) No major problems with the cover have been experienced to date, however, movement of the baffle used to create the two zones in the covered lagoon has presented a problem. This issue is considered in more detail in Appendix H. The main outcome is that securing of the baffle must be more substantial than the sand filled tubes used to weigh down the baffle in this lagoon.

### 7.2.2 *Research Operations*

Research operating requirements of the lagoons that are over and above those required for normal operation, are generally related to obtaining more accuracy from existing activities and extending the range of parameters that are controlled and monitored. These include characterisation of influent, sampling of lagoons constituents and effluent, accurate flow control and monitoring, accurate biogas measurement and measurement of sludge and scum development.

Lessons that have been learnt in this regard include;

1) Loading calculations based on grab samples of influent must take account the significant diurnal variation in flow and wastewater "strength" and hence require flow weighting.

2) Measurement and representative sampling of scum is difficult and can only provide "ball park" results.

3) Sludge layer sampling and analysis via Biochemical Methane Potential (BMP) assays must take into account the growing thickness of the sludge layer and relative microbial activity at various levels within this layer. The development of BMP assays for measuring biomass activity was not completed, however, preliminary results suggested a significant reduction in activity occurred from samples taken at the same location from the bottom of the lagoon while the sludge layer (and active biomass component) grew to higher levels.

## 7.3 Integration with Southern Meats' Treatment Facilities

Figure 1-1 shows where the research lagoons fit into the wastewater treatment scheme at Southern Meats. The research lagoons effectively increase the anaerobic treatment capacity of the system (COD, TSS and O&G

removal) and in doing so reduce the potential organic loading on the subsequent aeration and settling lagoons.

Table 7-1 illustrates the improvement the lagoons make to the capacity of the anaerobic stage of treatment at Southern Meats. As can be seen, the existing anaerobic lagoon is already operating at its design limit on one shift operation. For two shift operations the existing lagoon is pushed beyond its capacity. The expansion of the anaerobic treatment stage, provided by the trial lagoons, is desperately required.

In terms of other wastewater quality characteristics (nutrients, TDS and pH) the research lagoons perform the same as the existing anaerobic lagoon and hence make no differing impact on the subsequent treatment stages than does the existing anaerobic lagoon.

Table 7-1. Summary of Flow and OLR's for Anaerobic Treatment Stage at Southern Meats.

| **Abattoir Operation** | **Wastewater Flow ($m^3.d^{-1}$)** | | |
|---|---|---|---|
| Single Shift | 1,000 to 1,200 | | |
| Double shift | 1,400 to 1,600 | | |
| **Lagoon** | **Flow Capacity ($m^3.d^{-1}$)** | **OLR (1) ($kgCOD.m^{-3}.d^{-1}$)** | **COD Removal (1) (%)** |
| Southern Meats' lagoon (Lagoon 3) | 1,050 | 0.7 | 75 |
| Covered lagoon (Lagoon 1) | 600 | 1.2 | 80 |
| Uncovered lagoon (Lagoon 2) | 250 | 0.5 | 80 |
| Total | 1830 | - | - |

(1) Nominal operating performance expected.

# 8. COST/BENEFIT ANALYSIS

The basic capital costs of the covered and uncovered trial lagoons is presented in Section 8.1 along with comparative estimates of two commercially built covered and uncovered lagoons. As expected, the covered lagoon is significantly more expensive.

Section 8.2 considers the operating costs associated with anaerobic lagoons which shows little difference between a covered an uncovered lagoon.

Section 8.3 considers the costs and savings that could be made by utilising the biogas in boilers for heat and steam at the abattoir using Southern Meats as a case study. The result, over a nominal 5 year period, is a significant reduction in costs when applying the covered anaerobic lagoon technology over conventional uncovered lagoon technology. Over a 15 to 20 year life, which could be expected of such plant, the costs savings may even turn into a financial return.

## 8.1 Construction Costs

The budget construction costs of the two 3,000 $m^3$ lagoons are presented in Table 8-1. Also shown are estimates of a single 3,000 $m^3$ covered lagoon and a 6,000 $m^3$ uncovered lagoon (equivalent in performance to the 3,000$m^3$ covered lagoon).

Table 8-1 Construction Costs and Budget Estimates

| Component | Actual 2 x 3,000 $m^3$ Trial Lagoons | Estimate 1 x 3,000 $m^3$ Covered Lagoon | Estimate 1 x 6,000 $m^3$ Uncovered Lagoon |
|---|---|---|---|
| Earthworks (1) | 65,000 | 35,000 | 60,000 |
| Mech & Elec | 45,000 | 30,000 | 30,000 |
| Cover and Baffle | 100,000 | 100,000 | 0 |
| Flare System | 60,000 | 60,000 | 0 |
| Total ($) | 270,000.00 | 225,000.00 | 90,000.00 |
| Flow (kL) (2) | 900 | 600 | 600 |
| Cost ($.$kL^{-1}$) (3) | 300.00 | 375.00 | 150.00 |

(1) Value of land used for lagoon not included in above figures.
(2) Based on OLR = 0.6 and 1.2 $kgCOD.m^{-3}.d^{-1}$ for uncovered and covered lagoons respectively.
(3) Capital cost per kL of wastewater treated.

Based on the basic costs shown in Table 8-1 and comparing the 3,000$m^3$ covered lagoon with the 6,000 $m^3$ uncovered lagoon, it can be seen that the simple uncovered lagoon is significantly cheaper to build. A significant advantage of the covered lagoon, however, is the reduction of odour which is difficult to put a value on. The potential for biogas utilisation (Section 8-3) will also off-set the cost of a covered lagoon and over a 15 to 20 life would prove to be more economic.

These figures, however, are only preliminary. The earthwork costs will vary dramatically, depending local topography and land availability for the lagoons. Pipework and pumping costs in the Mechanical & Electrical group may also vary depending on the distance from wastewater source to the lagoon. The cost of the remaining items should not change significantly from site to site but will vary depending on the size of the installation. All these aspects at Southern Meats' are considered fairly typical of Australian abattoirs and thus these costs should provide reliable "ball-park" figures.

It should be noted that these costs include aspects of design which are not required for normal operation or which have not been proven to date. Should these not be required then costs could be reduced as follows;

- Sludge Recycle
  – To be demonstrated in project extension.
  – If removed $10,000 of Mech and Elec costs could be saved.

- Full Cover
  – It has been proposed from Laboratory Studies that only a partial covering of the lagoon may be required (ie. 1/3 rd of lagoon surface). If this were done $50,000 could be saved on a 3,000 $m^3$ lagoon.

- Flowmeters
  – These were installed for research needs. While preferable in an operational system they are not essential. If removed $15,000 of Mech & Elec costs could be saved.

- Pipework
  – A complex pipework system was installed to provide flexibility in operation durng the research trials. This could be dramatically simplified for normal operational installations.

## 8.2 Operating Costs

The operating costs associated with the trial anaerobic lagoons are related to the following activities;

- Sludge recycle pump;
- Effluent pumps;
- LPG supply for flare system;
- EPA sampling and monitoring requirements;
- Miscellaneous electrical consumption for controls, switchboards, flowmeters, fans, etc...;
- Monitoring and analysis; and
- Operation and maintenance.

None of the above costs are significant in terms of overall abattoir management and operation. Table 8-2 provides an estimate of the larger of these costs assuming the lagoons are being operated as commercial facilities and not research facilities. It is anticipated that operating costs would not vary significantly with size and consequently such costs become relatively smaller as the size of the facility increases.

Table 8-2. Major Operating Costs for Trial Anaerobic Lagoons (1)

| Item | Quantity | | Cost | |
|---|---|---|---|---|
| | | | per unit | per annum |
| Sludge Recycle Pump (1 x 1.5kW motor) | 28 | $hrs.wk^{-1}$ | 0.15 $\$.kwh^{-1}$ | 250.00 |
| Effluent Pumps (2 x 3 kW) | 60 | $hrs.wk^{-1}$ | 0.15 $\$.kwh^{-1}$ | 1,000.00 |
| LPG Supply | 1 | $cylinder.yr^{-1}$ | 60.00 $\$.cylinder^{-1}$ | 60.00 |
| Operation and Maintenance | 2<br>1 | $hrs.wk^{-1}$<br>materials | 30.00 $\$.hr^{-1}$ +<br>500.00 $\$.yr^{-1}$ | 3,480.00 |
| EPA Monitoring (2) (monthly off-site) | 12 | $samples.yr^{-1}$ | 221.00 $\$.sample^{-1}$ | 2,652.00 |
| EPA Monitoring (2) (fortnightly on-site) | 6<br>1 | $hrs.sample^{-1}$<br>materials | 30.00 $\$.hr^{-1}$ +<br>600.00 $\$.yr^{-1}$ | 5,280.00 |
| **Total** | | | | **12,722.00** |

(1) Costs are based on commercial operation of lagoons, not research based operation, and assuming 20% sludge recycle is applied.
(2) EPA monitoring cost estimates are for anaerobic lagoon only and do not include monitoring for other stages of treatment system.

## 8.3 Biogas Utilisation

Though biogas production has not been accurately measured (Section 5.4), an estimate of the potential value of the biogas resource can be made based on results from the Laboratory Studies, COD mass balance (Section 6.2) and data from other research. Table 8-3 summarises this information for the following two cases;

- The present 3,000 $m^3$ trial anaerobic lagoon; and
- A hypothetical covered lagoon of 9,000 $m^3$.

Table 8-3. Estimated Biogas Production

| Lagoon Size ($m^3$) | Wastewater Flow ($m^3.d^{-1}$) | Organic Loading Rate ($kgCOD.m^{-3}.d^{-1}$) | Biogas Produced(1) ($m^3.d^{-1}$) | LCV (2) ($MJ.m^{-3}$) |
|---|---|---|---|---|
| 3,000 | 500 | 1.0 | 900 | 20 |
| 9,000 | 1,500 | 1.0 | 2,700 | 20 |

(1) Gas production calculations based on the following assumptions;
- COD removal = 75 %
- Gas production rate = 0.25 $m^3CH_4.kgCOD_R^{-1}$
- Biogas methane content = 63% v/v

(2) LCV – Lower Calorific Value @ STP

Assumed values for the variables affecting the amount of biogas produced have been listed in Note (1) of Table 8-3. The effect these variable may have is listed as follows;

- The COD removal of 75% is conservative and could be considered a minimum. Any increase in this would improve gas production.
- The gas production rate of 0.25 $m^3CH_4.kgCOD_R^{-1}$ is conservatively less than the theoretical value of 0.35 $m^3CH_4.kgCOD_R^{-1}$ (Speece 1996) but is of the order produced in laboratory studies. Again, any increase in this would improve gas production.
- The biogas methane content of 63% is the average content as measured on-site (Section 5.4).

Based on the biogas production in Table 8-3, a hypothetical boiler selection has been made and budget costs established. This is presented in Table 8-4. Note, this information is based on a 12 hour per day operation of the boiler, meaning that biogas storage would be needed. It may be feasible that this could be achieved under the cover of the lagoon, although this is not normally done. Biogas scrubbing equipment may also be required depending on the level of minor gas contaminants such as $H_2S$ and water vapour present in the gas. Measurement of such contaminants has not been made in this project.

The value of using the biogas in a boiler can be seen by considering the output of the biogas boiler with the natural gas boilers used at Southern Meats (Table 8-5). By comparing Table 8-4 and Table 8-5, it can be seen that the 3,000 and 9,000 $m^3$ covered lagoons would provide basic payback periods of approximately 14 and 11 months, respectively.

A more detailed analysis, however, should include the following costs not considered in the above comparison;

- covered lagoon operating costs;
- boiler operating costs;
- biogas storage; and
- inclusion of biogas scrubbing equipment.

Table 8-4. Boiler Selection and Costs (1)

| **Lagoon Size ($m^3$)** | **Standard Size Boiler (kw)** | **Boiler Model No.** | **Evaporation ($kg.h^{-1}$ F @ A 100°C)** | **Budget Cost(2) ($)** |
|---|---|---|---|---|
| 3,000 | 500 | 500EGN /1000 | 800 | 110,000.00 |
| 9,000 | 1,250 | 1.25MDGN /1000 | 2,000 | 220,000.00 |

(1) Information supplied by Maxitherm Boilers Pty Ltd (02) 9792 1011.
(2) Budget Cost is for supply and installation but does not include gas storage if required.

Despite the fact that including such figures might increase the payback period to 2 or 3 years, the potential value of utilising the biogas remains economically favourable, particularly for the larger, centralised meat processing facilities that are becoming more common in Australia.

Other industries in Australia, such as municipal wastewater treatment (SA Water, Melbourne Water) and breweries (Castlemaine, Brisbane), already collect and utilise biogas from anaerobic waste treatment processes successfully and there are many other examples around the world. This further supports the potential value of such a practice in the meat processing industry.

Table 8-5. Comparison of Biogas Boilers and Southern Meats' Boilers.

| Boiler Model | Max. Power Output (kW) | Daily Energy Output ($kWh.d^{-1}$) | Average Daily Gas Used ($m^3.d^{-1}$) | Value of Natural Gas Used (1) ($\$.yr^{-1}$) | Percentage of Natural Gas Used (%) |
|---|---|---|---|---|---|
| Southern Meats' Boilers (2) | | | | | |
| "Fire Tube" | 8,000 | 53,600 | 5,660 | 743,000 | 100 |
| "Water Tube" | 7,000 | 40,600 | | | |
| Biogas Boilers (3) | | | | | |
| 500EGN/1000 | 500 | 5,000 | 900 | (65,700) (4) | 8.8 |
| 1.25MDGN/1000 | 1,250 | 12,500 | 2,700 | (197,100) (4) | 26.5 |

(1) Based on Natural Gas cost = $0.36 per kL and 365 $d.yr^{-1}$ operation of one boiler per day.
(2) Performance data supplied by Thomlinson Boilers (02) 9681 4177.
(3) Performance data supplied by Maxitherm Boilers Pty Ltd (02) 9792 1011.
(4) Equivalent value of gas saved.

Table 8-6 reconsiders the basic capital costs given in Table 8-1 and provides an estimated 5 year capital/operating cost comparison between a covered lagoon using biogas utilisation and a conventional uncovered lagoon. The result is a significantly lower cost over the 5 years for the covered/biogas utilisation option.

As indicated, financial costs such as interest and depreciation, have not been considered. The project life could be expected to last for 15 to 20 years, however, providing even more scope for savings to be made and off-set financial costs.

Table 8-6 Comparison of Basic 5 Year Costs for Covered Lagoon (with biogas utilisation) and Uncovered Lagoon

| Component | Estimate | |
|---|---|---|
| | 1 x 3,000 $m^3$ Covered Lagoon | 1 x 6,000 $m^3$ Uncovered Lagoon |
| Earthworks (1) | 35,000 | 60,000 |
| Mech & Elec | 30,000 | 30,000 |
| Cover and Baffle | 100,000 | - |
| Boiler | 110,000 | - |
| Flare System | - | - |
| Total Capital ($) | 275,000.00 | 90,000.00 |
| Plus annual operating costs (2) | 75,000.00 (3) | 75,000.00 |
| Less annual savings (2) | 328,500.00 | - |
| Basic 5 Year Cost (4) | 21,500 | 165,000.00 |
| Flow ($kL.d^{-1}$) (5) | 600 | 600 |
| Cost ($\$.kL^{-1}.d^{-1}$) | 35.83 | 275.00 |

(1) Value of land used for lagoon not included in above figures.

(2) Based on operating costs of $15,000.00 per annum (Table 8-2) and natural gas savings of $65,700.00 per annum (Table 8-5) for a nominal period of 5 years.

(3) This costs assumes operating cost of boilers is absorbed in normal boiler operating costs and not associated with covered lagoon operation.

(4) Costs do not include interest, depreciation and other financial costs.

(5) Based on OLR = 0.6 and 1.2 $kgCOD.m^{-3}.d^{-1}$ for uncovered and covered lagoons respectively.

# 9. CONCLUSIONS

## 9.1 Review of Field Scale Trials

Despite the operational difficulties in achieving and maintaining satisfactory flow to the lagoons, results indicate that satisfactory, stable operation has been achieved to date, albeit at a lower loading than desired and represent the completion of Stage 1 of the Project. Organic removal (as COD) has been good and of similar order to laboratory studies. Operating parameters such as pH, VFA and Alkalinity are all within acceptable ranges and suggest successful start-up to a OLR of 0.5 $kgCOD.m^{-3}.d^{-1}$ has been achieved.

Solids analysis of the sludge layer in the lagoons shows satisfactory results and suggest a suitable concentration of biomass has been established.

Gas production figures are encouraging (although unreliable) and further point to a successful start-up. They also suggest that performance levels are similar those demonstrated in the laboratory may be achievable, which is a key objective of the field trials.

Based on a lower calorific value of 20 $MJ.m^{-3}$ and 24 $hr.d^{-1}$ boiler operation, the expected gas production of the fully loaded covered lagoon may represent up to 8.8% of Southern Meats' requirements while harnessing the potential gas production from the total wastewater flow may represent up to 26.5% of Southern Meats' requirements (Table 8-5).

Analysis of nitrogen shows ammonification of the organic N is occurring. This is illustrated by an increase in ammonia levels and decrease in organic N. As expected the nitrates and nitrites (NOx) are in low concentrations. The overall impact on total N removal was about 20%, presumably as settled solids.

Significant Phosphorous removal also occurred with results indicating accumulation in lagoon sediment and biomass. Present results show a 23% reduction in influent to effluent total P concentrations but results are inconclusive regarding the sustainability of this removal.

Oils and greases have been measured as hexane extractables. A significant reduction has been observed, although much of this has been removed to the scum layer building on the surface. Indications are that this scum layer is thicker over the active zone than the settling zone in the covered lagoon. It appears to have reached an equilibrium, however, where accumulation and degradation have reached a balance thus representing a sustainable process.

The temperature of the lagoons has followed ambient temperatures and flow rates. It was hoped that the high temperature of the incoming wastewater (35°C to 40°C) would help maintain elevated temperatures, however, due to the poor flow this has not been realised. Increasing flows and the coming of summer led to a reversal of the falling trend during the winter. No differentiation between the covered and uncovered lagoon has been evident to date[6].

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[6] Temperature observations over the period of December 1997 to February 1998 show a marked difference in lagoon temperatures with the covered lagoon up to 6°C higher. This will be monitored in the continuing trials.

## 9.2 Impact on Meat Processing Industry

The simple uncovered anaerobic lagoon has been the main treatment process for the meat processing industry. To their credit they are simple, inexpensive and responsible for the removal of the bulk of the organic carbon in abattoir wastewater. To their detriment they are easily overloaded and produce nuisance odours. Further, with increasing pressure on the aerobic lagoons to improve nutrient removal, the anaerobic stage must maintain an even higher level of organic carbon removal and desirably a high level of ammonification.

Covered anaerobic lagoons, with advanced processing features such as high activity zone, recycle and fixed film, have the potential to make a significant impact on the management of wastewater treatment in the meat industry by allowing the industry to retain the use of relatively simple anaerobic lagoons while reducing nuisance odours and maintaining (or improving) organic carbon removal and ammonification.

The main disadvantage of covered anaerobic lagoon technology is the higher capital cost, although this is significantly less than comparable high rate technology such as UASB technology. The higher cost, however, can be off-set by the following key initiatives;

- The reduced size of lagoon (due to efficiency in organic carbon removal) reduces the land requirements;
- The improved efficiency results in lower sludge yields and gives lagoons a longer operational life;
- Biogas recovery and utlisation in boiler or power generation can reduce power and heating costs;
- Improved operational reliability reduces the risk of damaging or overloading following aerobic treatment processes;
- Overall improvement to the treatment process is achieved reducing the need to increase buffering capacity in storage or irrigation land requirements; and
- Reduces the risk of polluting and subsequent prosecution.

Other benefits, such as odour reduction, may also result in costs savings, albeit intangible, through improved community perceptions and general improvement to the local environment.

Of further significance to the meat processing industry is the fact that covered lagoon technology can be retrofitted to existing anaerobic lagoons. This provides an effective way of upgrading or extending existing treatment capacity to a treatment system that is widely used in the industry.

The development of partially covered lagoon technology with fixed film media offers even more potential benefits for the meat processing industry. This concept has implications for reducing the cost associated with the cover and, with the potential for creating a dual anaerobic/anoxic or facultative lagoon, the nutrient removal capacity of the treatment system could therefore be improved significantly.

## 9.3 Intellectual Property

As has been identified, anaerobic lagoon technology is widely used in the meat processing and many other industries. Consequently, the basic concepts have wide industry ownership. Further, the concept of covering lagoons is also widely applied and can not be seen as a novel technological development.

The main scope for claiming intellectual property (IP) relates to the methods of improving the efficiency of organic carbon removal by the creation of zones, the application of a sludge recycle regime and the inclusion of fixed films. Again, these technological innovations are widely used in various applications and it is the specific method of application and the application to abattoir wastewater in which any claim for IP may be made. As yet, however, the ability of such innovations to improve performance has not been conclusively demonstrated and so any claim for IP can not be made. It is anticipated that the completion of Stage 2 (currently underway) will provide this to some degree.

The greatest scope for innovation and subsequent claims for IP is in the development of fixed film, partial lagoon coverage and potential dual role lagoons which can contribute to nutrient removal.

## 9.4 Scope for Commercialisation

With such a wide application to the meat processing industry and many others, there is significant scope for commercialisation of the technology. Like IP, however, the completion of Stage 2 is required before the full demonstration of the technology is achieved and commercialisation can be pursued. It is most likely, that the main form of commercialisation will be in consulting and advising on new and retrofitting covered anaerobic lagoon projects.

## 9.5 Dissemination of Technology

The project has received a great deal of interest from a range of interested parties through several avenues of communication. Within the CRC there is general interest in intensive rural industry waste management issues and through the CRC's involvement in various other projects adressing such issues this project has received a wide, but informal, exposure.

Following the completion of the Laboratory Studies an Environmental Issues Seminar was held by the MRC on 17TH October 1996. At this seminar the CRC presented the results of laboratory studies, indicating the potential of the technology, and gained an enthusiastic interest from industry representatives present.

An Interim Report on the field trials was provided in August 1997 and this was later released through the MRC's "Envirofacts" bulletin to the meat industry. This generated further inquiries from industry and demonstrates the level of interest in the technology.

The CRC has also received valuable and positive feed back from Southern Meats who have a more direct involvement in the project, but who none-the-less, have a strong industry point of view. Ignoring initial design and commissioning problems, the covered anaerobic lagoon has proven to be a valuable and reliable part of Southern Meats treatment system, despite only being loaded to a nominal level well below its full capacity.

Members of the CRC, not directly involved in the project, also expressed interest in the technology following a presentation at the CRC's annual meeting. In particular, Clean-Up Australia Chairman (Ian Kiernan) expressed an interest in developing the biogas utilisation aspect of the project.

It is recommended that a further industry brief be provided by the MRC through their "Envirofacts" bulletin. A technical paper for peer review is being prepared by the CRC for release in the near future and it is recommended that a meeting of the TRC be convened to discuss the results and consider the continuing trials.

## 10. PROJECT FINANCIAL SUMMARY

The final closing balance of the project is given in Table 10-1, below. Expenditure on upgrading works and continued research in 1998 is covered by the project extension budget (Appendix B).

Table 10-1. Closing Project Balance

| Closing Project Balance @ 16th February 1998 | Cash Expenditure | In-Kind Expenditure |
|---|---|---|
| **CWWT – UNSW** | | |
| Labour | $181,004.00 | $26,211.00 |
| Equipment | $22,480.00 | |
| Analysis | $45,516.00 | |
| **WEL** | | |
| Analysis | - | $90,000.00 |
| **Southern Meats** | | |
| Labour & Materials | - | $30,000.00 |
| **Total** | **$249,000.00** | **$146,211.00** |
| Allocation | $249,000.00 | - |
| **Balance** | **$0.00** | - |

# 11. SUMMARY OF RECOMMENDATIONS

This section summarises the key recommendations made or implied in this report.

**Covered Anaerobic Lagoon Field Scale Trials**

The immediate recommendations resulting from trials to date are;

- Upgrade wastewater distribution system and extend trials to 1.2 $kgCOD.m^{-3}.d^{-1}$ organic loading (see Proposal for Project Continuation);
- Complete commissioning and carry out trials of fixed film pilot plant reactor to 2.4 $kgCOD.m^{-3}.d^{-1}$ organic loading;
- Prepare journal paper for peer review and publication; and
- Present a report in the MRC's "EnviroFacts" bulletin.

In continuing the trials, the following recommendations are made regarding the operation, sampling and anlaysis of the lagoons and pilot plant;

- Biogas system pressure should be operated at +1 to -3 mm $H_2O$ with set point at -1 mm $H_2O$;
- Better characterisation of abattoir wastewater is required to allow more accurate assessment of OLR;
- Improve data collection and analysis of sludge and scum layers for COD, TSS/VSS and O&G;
- Further development of BMP assay for assessment of microbiological activity is desireable;
- Odour measurement and comparison of covered lagoon vent gas and flare exhaust gas should be carried out;
- Convene a meeting of the Technical Review Committee to consider results and project continutation;

**Biogas Utilisation**

To further investigate the potential for biogas utilisation it is recommended that;

- Biogas production rates be better established;
- Biogas be analysed for minor constituents (eg. water vapour, $H_2S$, etc...); and
- A more detailed economic assessment of biogas utilisation be carried out.

**Future Technology R&D**

It is recommended that;

- Consideration should be given to extending the field trials (beyond current proposal for extension) to demonstrate the performance of fixed film technology and partial lagoon covering at field scale; and
- Interest in a demonstration project of boiler operation or power generation using biogas should be pursued.

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