University of Southern Queensland
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Biogas Generation from an Anaerobic Pond "Abattoir"

A dissertation submitted by

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Abstract

Management and treatment of abattoir wastewater is essential for effluent disposal processes. Since abattoir wastewater contains very high concentrations of organic matter, suspended solids, nitrogen and phosphorus, the potential environmental impact is of great concern to all communities. Efforts are being made to attain a high quality effluent by utilising biological treatments using anaerobic ponds. In doing so, biogas production is harnessed and electricity generation is utilised.

The research paper provides background research with a detailed review of available literature in the use of covered anaerobic ponds, conducted for the Churchill Abattoir to treat their high strength abattoir wastewater. An analysis of the performance of the wastewater treatment system, with emphasis on covered anaerobic ponds and effluent quality, was conducted with assistance from on-site measurements taken from the abattoir.

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Terminology and Abbreviations

Aerobic Digestion – Digestion processes that take place in the presence of oxygen

Anaerobic Digestion – Digestion processes that take place in the absence of oxygen

Biological Oxygen Demand (BOD) – A measure of the amount of oxygen that is consumed during the biological processes that break down organic matter within the wastewater

Chemical Oxygen Demand (COD) – A measure of the capacity of water to consume oxygen during digestion processes of organic compounds and to oxidize inorganic compounds within the wastewater

CH_4 - Methane

CO_2 – Carbon Dioxide

Fixed Solids (FS) – Inorganic compounds (N, P, K, Ca, Cu, Zn, Fe, etc.) in a suspended or dissolved state

GHG – Greenhouse Gas

H_2S – Hydrogen Sulphide

pH – A measure of the alkalinity or acidity within the wastewater

Total Dissolved Solids (TDS) – Organic or inorganic substances contained in an ionized suspended form

Total Kjeldahl Nitrogen – The sum of organic nitrogen and ammonia nitrogen within the wastewater

Total Suspended Solids (TSS) – Fine, inorganic mass particles suspended within the wastewater

Volatile Suspended Solids (VSS) – Organic matter removed or stabilised during treatment

Chapter 1 Introduction

1.1 Outline

This research has been made to determine the potential biogas production and effluent quality that is expected at the Churchill Abattoir, from the wastewater treatment system using anaerobic ponds. BioWin simulation software was used to give accurate estimations and provide guidelines for improved biogas production for the wastewater treatment system.

1.2 Background

A series of covered anaerobic ponds have been designed and constructed, and are to be appropriately monitored for potential biogas production. The ponds have been designed to treat the high strength wastewater that is produced from the Churchill Abattoir. The anaerobic digestion treatment process is utilised to enhance biogas quality and production for the use of electricity generation. Certain processes are involved in the digestion of the raw wastewater entering the ponds from the abattoir, which highly influences the production and quality of the biogas. The production of biogas by covering the ponds will reduce Greenhouse Gas emissions and control odour. The digested wastewater effluent will be used for land application purposes such as agricultural irrigation, and wash down water used in the holding yards at the abattoir.

1.3 Aim

This project aims to provide sufficient literature and research on the current wastewater treatment system used at the Churchill Abattoir, (located in the South East Queensland Brisbane region of Ipswich). It is proposed to give a guideline of the technology, in order to make recommendations to improve the system, by providing estimations of potential biogas production and an indication of the expected effluent quality for suitable effluent disposal processes. The feasibility of bio-energy production from the covered anaerobic ponds was determined and sufficient technical research and information on the performance of the technology is to be provided for the meat and livestock industry via Meat and Livestock Australia.

1.4 Objectives

The objective of this research is to present an outline and guideline for what is to be expected of the new, re-designed wastewater treatment system used at the Churchill Abattoir. It is required to provide an accurate estimation of how much biogas the covered anaerobic ponds will be able to produce, along with recommendations to maximise biogas production. Effluent quality will be determined with help from the BioWin software along with the biogas production rates. Also, conclusions will be made for the best utilisation methods for electricity generation. From this, recommendations will be made for the most feasible solution for maximising biogas production and reducing environmental impacts, such as Greenhouse Gas emissions (GHGs). This research may also be used for future reference and future work to follow on, as to relate it to specific criteria for all wastewater treatment processes for the Australian red meat abattoir industry.

1.5 Project methodology/justification

Both theoretical analysis and empirical techniques were used for the research of the project. When conducting the research, only the most relevant information with respect to anaerobic digestion for biogas production was considered. The methodology for deciding on the appropriate information was made from selecting information only from recognised and reliable sources. Some of the information relates to empirical approaches to the design of the anaerobic digestion ponds and are found to be applicable to this specific project.

1.6 Hypothesis

It is hypothesized that the most dependant parameters for biogas production and quality during anaerobic digestion processes are temperature and pH, pond design and influent substrate. To maximise the biogas production and enhance the methane content within the biogas, the temperature and pH must be kept at a stable constant in order to maintain optimum methanogenic bacterial activity. The pond system design should consider the appropriate flow rates for correct sizing and volumes to be verified. This will affect the hydraulic and solids retention times, as well as the start-up time and biomass yield (biogas produced). The influent substrate (raw wastewater) from the abattoir must undergo appropriate screening (for solids removal) and other pre-treatment processes before being pumped to the anaerobic ponds, to minimise solids within the wastewater. This will shorten the hydraulic and solids retention times and will reduce excess settling and clogging within the ponds.

1.7 Summary

This dissertation aims to provide guidelines to enhance the biogas production and quality of biogas, from the wastewater treatment system, for the use of generating electrical power at the Churchill Abattoir. From the BioWin software, accurate estimations for the expected biogas production and quality will be determined. However, the results cannot be compared to the literature provided as a background to aid in the understanding of the anaerobic digestion processes, since the software is for educational purposes only.

The following chapters provide the appropriate information relating to this project through the anaerobic digestion processes for the Churchill Abattoir wastewater treatment system. Following, the modelling and simulation of the treatment system along with results and discussions provide a detailed analysis of this study.

Chapter 2 Background

2.1 Introduction

The study of wastewater treatment processes for biogas production is quite extensive. The literature available mainly focuses on municipal and industrial wastewater treatment. However, within Australia the research conducted is very limited for the treatment of high strength abattoir wastewater in the red meat industry. This chapter summarises the biological processes and environmental considerations that influence the digestion processes through the use of wastewater treatment ponds. During these processes, the same principals apply to all wastewater treatment; however this research emphasises high strength abattoir wastewater treatment processes with the use of covered anaerobic ponds.

2.2 Biogas generation processes

Biomass is biological material derived from living, or recently living organisms. Chemical or biological processes break down the initial material producing biofuels such as methane gas, ethanol liquid or charcoal solid (Twidell & Weir, 1986, p. 281). This biogas is a product of anaerobic digestion or fermentation processes, where the biodegradable materials are processed from plants, humans, marine life, and animals. Solar radiation in photosynthesis captures the initial energy of the biomass-oxygen system. The photosynthesis process by living organisms converts light energy into chemical energy. Photosynthesis is arguably one of the most important renewable energy processes, since nearly all life depends on it.

Biogas generation from the use of wastewater treatment ponds includes many different processes and designs. However, the most common technique for the production and utilisation of biogas from wastewater treatment ponds is the use of anaerobic digestion processes. Anaerobic digestion is a biochemical process for producing energy from biomass. Fermentation or digestion processes produce carbon dioxide, CO_2 and carbon fuel methane, CH_4, through the multi-stage biological treatment process where bacteria decompose organic matter in the absence of oxygen. Wet, warm and dark conditions enhance fungi and bacteria to decompose biomass and animal wastes down to primary nutrients and soil humus.

Under anaerobic conditions the process occurs in two stages, involving two different types of bacteria. The first stage consists of acid forming bacteria converting the organic material present in the feed sludge to organic acids (also called volatile fatty acids). During the second stage, methane and carbon dioxide are converted from these organic acids, which serve as the substrate (food) for anaerobic methane-producing bacteria.

Many different processes aim to produce beneficial fuels at economical prices. Green wood has a net energy density available in combustion ranging from about 10MJ/Kg, where as fats and oils range from about 40MJ/Kg and methane from 55MJ/Kg (Twidell & Weir, 1986, p. 282). Economic biofuel production is mostly favoured when process materials are already concentrated, allowing for low cost availability.

Biogas productions are most economically favourable when the digester is placed in a flow of biomass material already present. Such flows are associated with:

- Sewage systems
- Piggery washings
- Cattle shed slurries
- Abattoir wastes
- Food processing residues
- Municipal refuse landfill dumps

2.3 Anaerobic digestion considerations

During anaerobic digestion processes, most of the energy transferred to the methane produced is obtained from the volatile fatty acids. Optimum operational conditions must be maintained, due to the growth rate restriction from the low yield obtained from volatile fatty acids by methane-producing bacteria, in order for satisfactory destruction rates and methane production. Important operational conditions must be taken into great consideration, regularly monitoring and maintaining any changes in alkalinity, pH, and temperature, in order for the methane-producing bacteria to range in their optimum activity. Some of the conditions are volumetric organic loading rate, biomass yield, hydraulic retention time (HRT) and solids retention time (SRT), start-up time, and environmental factors, that affect the production of biogas through anaerobic digestion processes. Both aspects of the wastewater treatment and the resource recovery processes must be examined through the important factors that govern the anaerobic digestion process.

2.3.1 Volumetric organic loading rate

The volumetric organic loading rate is the input rate of raw materials into the anaerobic pond, in terms of material weight per unit volume per unit time. In designing or sizing of anaerobic systems, VOLR is one of the most important factors to consider. VOLR is given by the following expression:

$$\boldsymbol{VOLR = \frac{C_i Q}{V}}$$

Equation 1

where C_i is the in-flow substrate biodegradable chemical oxygen demand (COD) concentration (mg/L), Q is the substrate flow rate (m^3/day), and V is pond volume (m^3). Based on on-site testing, C_i and Q are known parameters, and VOLR is determined. The volumetric organic loading rates to the ponds are also expressed in terms of volatile solids (VS).

2.3.2 Biomass yield

Biomass yield is defined as the ratio of the amount of biomass produced in a system to the amount of substrate consumed. The production of volatile acid during anaerobic digestion results in the production of methane (Geradi, 2003, p. 71). New bacterial cells or sludges are produced, as wastes are degraded. It is mathematically represented below as the biomass yield:

$$\boldsymbol{Y = \frac{\Delta X}{\Delta S}}$$

Equation 2

where ΔX is biomass concentration produced in the system (mg VSS/L), and ΔS is the consumed substrate concentration in the system (mg COD/L).

2.3.3 Hydraulic Retention Time and Solids Retention Time

The time that the wastewater remains in the pond is known as the Hydraulic Retention Time (HRT). Waste compounds such as sugars are readily degradable, requiring low HRT. However, complex wastes such as chlorinated organic compounds require longer HRT for their metabolism. The Solids Retention Time (SRT) is the time the activated solids remain in the pond. Both HRT and SRT are usually expressed in days.

2.3.4 Start-up time

Considerations must be taken to the start-up time of the anaerobic digestion process due to the slow growth rate of anaerobic microorganisms. Normal performances of the biological treatment system can be achieved through continuous substrate feeding. Facultative anaerobes, which are bacterium capable of living and growing in the presence as well as the absence of oxygen, and anaerobes including methane-producing bacteria must be employed adequately to seed in an anaerobic pond. The facultative anaerobes are highly concentrated in the secondary sludge, and the primary sludge not only supplies some facultative anaerobes but also many anaerobes including methane-producing bacteria and many organic particulates (Geradi, 2003, p. 81). The primary sludge must supply a copious amount of methane-producing bacteria, since the secondary sludge cannot seed alone and methane-producing bacteria die quickly in an activated sludge process.

2.3.5 Limitations of anaerobic digestion processes

There are some limitations for the anaerobic digestion processes, where the influent substrate and temperature are important parameters. In some cases, the raw wastewater entering the digester cannot be altered in any way, so no enhancements to the microbial activity can be made. This will limit the production and quality of the biogas. Also, the temperature is usually unchangeable since, for example, the covered anaerobic ponds are subject to ambient conditions. The only change in temperature that can be made is for it to be increased by a heat addition. In doing so, a high energy input is required which may be infeasible for some systems.

2.3.6 Environmental factors concerning anaerobic digestion

There are certain environmental factors that affect the performance and production of biogas during anaerobic digestion processes. These dependant factors are highly influential to one another and are the driving parameters for the digestion process.

The temperature in an anaerobic pond must be sustained at an acceptable and uniform optimum, to prevent undesired bacterial activity. Methane-producing bacteria will be biologically affected with any slight deviation of even a few degrees. In order to prevent the development of temperature variations within the system, sufficient mixing of the activated sludge is required.

During the final process of anaerobic digestion, methanogenic bacteria produce methane, carbon dioxide, hydrogen and acidic acid. The methanogenic bacteria are very sensitive to both temperature and pH, and this is one of the most influential processes for the production and quality of the biogas. The species of bacteria that are present at each stage of temperature range are listed below.

- **Psychrophilic** bacteria exist at temperature ranges below 20^oC. Volatile fatty acid production will continue at depleted temperatures as low as 10^oC, but methane production will proceed slowly and may even be nonexistent.
- **Mesophilic** bacteria exist in temperature ranges between $20\text{-}40^oC$, and can be sensitive to sudden temperature changes. This is the most common temperature range that anaerobic digestion systems are designed for, due to the stable supply of biogas that can be produced. The optimum temperature that should be maintained in the digestion system is 35^oC, and close attention should be paid to the volatile acid-to-alkalinity ratio if this temperature drop occurs.
- **Thermophilic** bacteria exist between temperature ranges of $40\text{-}75^oC$, and are considered to be less stable and more sensitive to environmental fluctuations. The rate of yield due to the increased temperature is high; however a high energy input is required to maintain the high temperatures.

Since anaerobic ponds are subject to the ambient environment, temperatures are more likely to range anywhere between 10^oC and 35^oC in areas such as South East Queensland.

Pure methane produces an odourless, clean burn (Equation 3), with a heat value of about $38MJ/m^3$. However, the methane content is mixed with carbon dioxide, after anaerobic digestion. The carbon dioxide mixed with the methane reduces the heat value to approximately $19\text{-}23MJ/m^3$, which is much lower than that of pure methane (Geradi, 2003, p. 73). This means that the volume of biogas must be almost twice that of pure methane, to deliver the same energy. The usual level of pH of the activated sludge within the pond should be maintained between 6.4-7.8 (Green, p. 57) for appropriate bacterial growth.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Equation 3

2.4 Environmental impacts

Greenhouse gases absorb heat from solar radiation that is radiated off the earth's surface. This heat is trapped in the earth's lower atmosphere, causing global climate change. Certain gases like carbon dioxide, methane, nitrous oxide, hydrofluorocarbons and sulphur hexafluoride are most effective at absorbing this radiated heat. The global warming potential for these gases, with respect to that of carbon dioxide, are shown below in Table 1 (Stewart & Trangmar, 2008). The potential of the gases differ from their ability to absorb the heat radiated from the earth, and the factors are dependent on the lifetime over which the effect of the gas is assessed.

Values for the global warming potential are usually taken from the 100 year period, where, for example, 1kg of methane gas is estimated to have 21 times the global warming potential to that of 1kg of carbon dioxide.

Table 1. Global warming potentials

Gas	Global Warming Potential Relative to Carbon Dioxide		
	20 years	**100 years**	**500 years**
Methane	72	21	7.6
Nitrous Oxide	310	295	153
Hydrofluorocarbon – 134a	3830	1,430	435
Hydrofluorocarbon – 23	12,000	14,800	12,200
Sulphur hexafluoride	15,100	22,800	32,600

2.4.1 Greenhouse Gas emissions from animal waste

The most concerning greenhouse gases produced from animal waste are carbon dioxide, methane, and nitrous oxide.

The decomposition of animal wastes result in carbon dioxide (CO_2) emissions, in the presence of oxygen. These aerobic conditions allow bacteria to oxidise the biodegradable carbon in the animal waste to carbon dioxide. The carbon dioxide emissions emitted from the decomposition of animals should not add any net change in the global greenhouse gas balance. This is because the carbon dioxide that has been oxidised will have been ingested by the animals as food, which will have absorbed carbon dioxide from the air during photosynthesis, therefore complementing the process as being renewable.

Biogas is obtained when organic carbon in animal waste decomposes under anaerobic conditions, where the biodegradable carbon is converted to a mixture of carbon dioxide and methane. As seen in Table 1, methane has a global warming potential 21 times greater than carbon dioxide; emissions must be controlled in order to maintain the carbon cycle. Controlling nitrous oxide (N_2O) emissions is essential due to its high global warming potential (see Table1). Nitrous oxide emissions can be particularly significant when animal wastes are applied to soil. The gas is produced due to the nitrification and denitrification of the organic nitrogen in animal waste (Stewart & Trangmar, 2008, p. 13).

2.5 Wastewater treatment processes using ponds

Some configurations of wastewater digestion ponds are outlined below. Each process may be used as a single system or in a multi-stage system, with a combination of each configuration. The influent substrate will enter the first pond in the system, where it will undergo the digestion process, and then the effluent wastewater from this pond will be fed into the consecutive pond and so forth, until the wastewater is completely digested and it is suitable for land application or other uses.

2.5.1 Anaerobic pond treatment

Anaerobic treatment processes consist of two functions that fulfil basic requirements for ideal operations. Firstly, volatile acids, carbon dioxide, hydrogen and bacteria cells are converted from soluble organic materials. This results in two classes of bacteria within this process:

- Facultative anaerobes, which are bacterium capable of living and growing in the presence as well as the absence of oxygen
- Obligate bacteria, which can only operate under conditions without oxygen

During the second process, methane-producing bacteria convert volatile acids (primary acetic acid) and other trace elements to methane gas and carbon dioxide. Environmental conditions must be controlled due to the methane-producing bacteria being highly sensitive to sudden changes.

It is common for a properly-designed anaerobic pond to achieve 80% reduction of both BOD and suspended solids. Due to the high influent BOD (approx. 2000 mg/L or higher), nutrients, temperature of about 40^0C and adequate fat which forms a scum layer to insulate the surface, anaerobic treatment is ideal for the treatment of abattoir wastewater. Anaerobic ponds should operate at a preferable pH ranging from 7.0 – 7.2, and should be designed to a minimum HRT of about 20 days to avoid short circuiting, allow for pond volume reduction caused by sludge build-up, and also to avoid shock loads (Green, pp. 57, 60). The figure below shows the mechanism of anaerobic treatment processes (Green, p. 58).

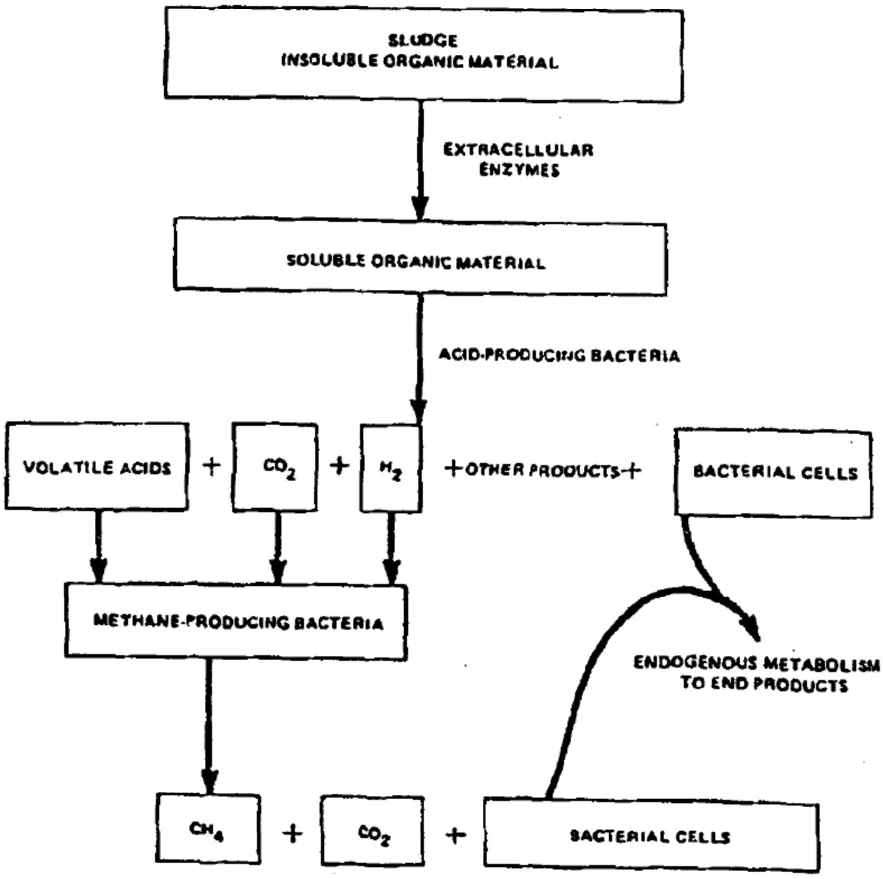

Figure 1. Mechanism of anaerobic sludge digestion

2.5.2 Facultative pond treatment

Facultative ponds consist of both anaerobic and aerobic processes. If the dissolved oxygen is maintained sufficiently, the ponds are generally odourless. An aerobic layer enhances anaerobic processes in facultative ponds. These conditions are achieved when the organic surface load is low (22 – 67 kg BOD/ha.day) (Green, p. 61). Secondary facultative ponds receive particle-free wastewater from anaerobic ponds, where the remaining unsettled BOD is oxidised by heterotrophic bacteria (Pseudomonas, Flavobacterium, Archromobacter and Alcaligenes spp) (Kayombo, Mbwette, Ladegaard, & Jorgensen, 2010, p. 8). Facultative ponds can achieve up to 95% BOD reduction, with a minimum detention time of 5 days (Green, p. 61).

2.5.3 Aerobic pond treatment

The effluent from an anaerobic pond is suitable for both facultative and aerobic ponds, with a BOD_5 strength of 200-400 mg/L. Aerobic ponds are designed based on the diffusion of oxygen into the surface without the aid of any mechanical aeration, and should operate with a BOD design loading of 45-90 kg BOD/ha.day. Algal growth is common in abattoir wastewater, due to the existence of phosphorous and nitrogen. If the wastewater ponds are placed in series with one another in the system, short circuiting will be minimised, retention times will be enhanced (15-20 days), and a reduction of pathogenic organisms such as coliform bacteria will be enhanced (Green, p. 64).

2.6 Assessment of consequential effects/implications/ethics

It is stated by the Institution of Engineers Australia that, *"Engineering is a creative process of synthesising and implementing the knowledge and experience of humanity to enhance the welfare, health and safety of all members of the community, with due regard to the environment in which they live and the sustainability of the resources employed"* (Ethics, 2009).

It is the responsibility of the engineer to have a sense of responsibility towards society with ethical and moral values. With respect to the community, engineers must act ethically in the interest of the community. The community should be considered in all aspects of context to compromise all groups in society. The engineer has the responsibility of loyalty to the employers or clients for whom they should apply their knowledge and skills with fairness, honesty and good faith. Adverse consequences will be informed to the employer or client, based on experienced engineering judgment, and taking reasonable steps to find alternative solutions (Ethics, 2009).

Ethical issues and consequences that apply to the design and planning of anaerobic digestion systems include traffic planning, emissions to air, ground and water contamination, noise pollution, visual impact and control of odour levels.

It is very important to have suitable access roads to the systems, for both during the construction and operation of the project. In this case the site is already under operation at the Churchill Abattoir and the accessibility to the ponds is already established.

A very important ethical issue regarding this project involves the measurement, control and the maintenance of the Greenhouse Gas emissions associated with the production of biogas, as well as the processing of the biogas as a renewable energy resource. These environmental considerations impact the community within the workplace as well as society as a whole. Any potential emissions to the atmosphere during construction or operation from vehicles etc will also be of concern. This also applies to the environment surrounding the anaerobic digestion systems causing contamination to the ground or water.

The noise must be controlled accordingly through noise regulations. The noise conditions of the environment must be identified prior to construction or operation, as well as expert advice being required to identify the potential noises of engines and pumps, etc, to appropriately design for noise reduction.

Other issues that may be of concern apply to the physical appearance of the ponds. This may be an issue in areas where the wastewater treatment system is located in a residential area. The ponds may have a high visual impact in built-up areas.

The odour control of anaerobic ponds is of great importance. With correct design, odour can be minimised, by completely covering the ponds using appropriate materials.

Other issues need to be considered with respect to corrosion of the operational equipment and storage systems of the design. This will highly influence the safety aspects of the project as well as future environmental impacts.

Environmental standards must be met in the workplace to conform to the Code of Ethics, which do not jeopardise the public welfare, and health and safety (Birse, 2000, p. 29).

2.7 Conclusions

A detailed literature review has been carried out for this study. It is seen that there is further work required for various aspects of the anaerobic digestion processes using covered ponds, for the use of high strength abattoir wastewater in Australian, for the red meat industry. Environmental factors that impact both the anaerobic digestion processes and the surrounding environment have been considered, and ethical issues have been discussed. All considerations of the wastewater treatment processes for anaerobic digestion using covered ponds have been the basis for the report that follows.

Chapter 3 Wastewater Treatment System at the Churchill Abattoir

3.1 Introduction

This chapter includes the process of the wastewater treatment system used at the Churchill Abattoir. It explains the composition of the raw wastewater and describes ways to handle and utilise the biogas as a renewable energy resource to generate electricity for on-site or other use.

3.2 Background

Previously, the wastewater treatment system utilised at the Churchill Abattoir consisted of two naturally occurring anaerobic ponds and one aerobic pond. The two anaerobic ponds were dimensioned to 40x80x5m and the aerobic pond to 80x120x2m. Firstly the raw wastewater from the abattoir was pumped directly into one of the anaerobic ponds then into the other. This then supplied the aerobic pond which produced quality effluent for the use of agricultural irrigation. The first two ponds were considered to be naturally occurring anaerobic ponds due to a large scum layer that had accumulated over the past several years since they were last clean. In some areas the scum layer was up to 1.5m thick, and prevented any oxygen to mix with the raw wastewater, which caused anaerobic digestion processes to occur. The ponds were originally designed to operate as one anaerobic pond, one facultative pond and one aerobic pond, and were to last at least

10-15 years before major cleaning. However, due to the high strength wastewater influent, the ponds failed to their design life after a period of about five years. The ponds were designed to the specifications and guidelines to that of systems designed for municipal wastewater and not for high strength abattoir wastewater from the red meat industry in Australia. A criterion for the treatment of high strength abattoir wastewater was not available at the time the ponds were constructed.

3.3 Slaughtering process at the Churchill Abattoir

The Churchill Abattoir slaughters about 600 head of cattle per day, and ideally the waste from each animal must be utilised in some way. Firstly, the cattle are kept in holding yards where they are washed by sprinklers to remove dirt and dust, and the floors of the holding yards are also washed to remove manure, dirt, grass and any other particulates that the animal has brought in to the holding yards. These washings add to the solids contained in the total wastewater being produced by the abattoir. The cattle are then sent to be slaughtered for their meat. During the slaughtering process, the animal is painlessly killed, bled, skinned, gutted and then boned.

The waste from each animal is employed though appropriate processes to either dispose of the waste or to produce useful products. After the animal has been bled, the blood is gravity fed to a cooking room, where it is cooked and then bagged for agricultural and fertilisation purposes. The skins are contained in bins where external customers buy them to produce leather and other products. During the gutting process, the gut is cut open and washed out to remove paunch, which is partially digested grain, grass and other materials that animal has recently ingested. The gut, or offal, is sent to the cooking room where it is cooked in a gas-fired rotary-drum cooker. The liquids are then separated from the solids and the solids are sent to be bleached to be used for food products. After being boned, the bones are augured through to a crushing machine to be crushed into small chips. A screening process follows this procedure to remove solids from liquids, i.e. blood, meat and bone. The figure below shows part of a carcass being augured to the crushing machine after the boning process.

Figure 2. Boned carcass being transported to the crushing machine

The paunch from the kill floor is washed and gravity fed to an open tank where it is then pumped to a separator that squeezes the paunch using a screw press machine, to separate liquids from the solids. There is about $90m^3$ per week of solid material produced from this separating process. Some of this dry solid material can be seen in Figure 3 below, which illustrates the partially digested matter as explained above. Another screening process separates the blood, meat and bone from the material that is produced from the crushing machine. The separator is a rotating screen drum, where water is used to wash the crushed solids through the screen. After all of these washing and screening processes, the wastewater and the separated liquids are then pumped to the wastewater ponds for treatment.

Figure 3. Dry paunch material after liquid separation

It is estimated that approximately 700m^3 per day of wastewater is being produced at the abattoir. The wastewater is composed of a mixture of hand wash water, sterilizer water (both from the kill floor mainly but other areas as well), which contains dissolved fats, blood, particulates, hair and dirt. As mentioned above, water from the separated paunch material is pumped to the ponds, and is composed of dissolved fats, oils and greases, and some grit. Stick water from the by-products of the blood room, fat rich water from the cooking process and tallow washing, along with general wash down water plus cleaning water containing chlorine compounds (about half the water used), are also included. Ash water from the boiler cooling tower (supplied from blow down water from the cooling towers), and also cattle yard wash down water containing manure, mud and sand add to the volume.

3.4 Covered anaerobic pond design

The main goal for anaerobic digestion is to optimise the growth of methane-producing bacteria (methanogenic bacteria) to generate high levels of CH_4 within the biogas. Different aspects play an important role in the production of quality biogas to produce a composition of approximately 70% CH_4. The collection and handling of the wastewater from the abattoir must be considered for the system design, including the amount of inorganic solids and water that are mixed with the total wastewater. Certain pre-treatment procedures such as screening, mixing, grit removal and solids separation are used to enhance biogas production from the anaerobic pond.

During anaerobic digestion processes, organic matter is broken down in the absence of oxygen by bacteria to produce biogas. The biogas from abattoir wastewater is expected to contain approximately 60-80% methane and 20-40% carbon dioxide, with some trace impurity gases such as hydrogen sulphide (H_2S). Since the biogas contains high amounts of methane it can be utilised in a number of different ways to harness its energy content of about 19-23 MJ/m^3 (Geradi, 2003).

The two anaerobic ponds that were constructed about a decade ago are now clogged and are being de-watered for cleaning, and the aerobic pond also requires cleaning due to years of solids settlement, which is beginning to cause clogging. There has been need for a new pond design and configuration in order to increase the life of the wastewater treatment system for the Churchill Abattoir. The new design for the wastewater treatment system utilises five (5) smaller ponds arranged in a *'cell'* configuration in series to one another. One pond is fed the raw effluent from the abattoir and the other ponds have a gravity feed from its adjacent pond. All of these ponds will be covered to harness the biogas released through anaerobic digestion processes. Each pond is sized to approximately 20x40x5m and the new system will completely substitute the original system. The smaller ponds offer easier cleaning procedures and cheaper construction and maintenance costs of the covers.

The list below summarises some of the important factors that must be considered for the pond design. These considerations must be taken before final construction and operation of the wastewater treatment system is underway.

- An assessment of the structural design of the anaerobic pond covers (shape, size, volumes) must be taken to ensure safe operation and to optimise the design for enhanced biogas production
- Materials used for the cover (High Density Polyethylene) need to be reviewed as the most appropriate material for the covers, for the best corrosion resistance
- Maintenance and access of the pond covers – for example, if there is a hole, is it easily repairable?
- Materials and parts used for fittings, valves, pipes, collecting equipment, etc
- Mixing – mechanical mixing (pumps, blades, two influent points). Energy input required for mechanical mixing (may require the use of the biogas produced to run pumps or electric motors). If no mechanical mixing is required, maybe the use of baffles may help to reduce any localised differences within the ponds and help with the mixing process to increase the production of the biogas and enhance the CH_4

- Sludge removal - scraping, de-watering, and any additional screening processes before the raw wastewater enters the ponds
- As far as the microbiology is concerned, the addition of specific anaerobes to "activate" the wastewater and shorten the start-up time may be considered
- Enhancing CH_4 content within the biogas will be dependent on a number of parameters (temperature, pH, volatile fatty acids, BOD, etc), along with the configuration of the pond design
- Document the pond performance by appropriate monitoring and sampling

3.4.1 Anaerobic pond cover

There are different configurations and designs for capturing biogas from wastewater treatment ponds. The simplest and cheapest option is an anaerobic pond cover. Each pond is lined with appropriate clay in order to prevent any leakage or seepage into groundwater or nearby waterways, which may cause contamination. The covers are made from High Density Polyethylene (HDPE) since this material is the best selection for corrosion resistance in wastewater treatment systems at this time, (Stewart & Trangmar, 2008, p. 27), and are to be structurally made from agricultural polyethylene pipe, as shown in Figure 4 below. The biogas is captured by placing the floating covers over the ponds. The production rates of biogas vary based on the temperature of each pond, which is dependently related to the daily and seasonal changes in ground temperature, ambient temperature, and influent temperature. A major disadvantage of the covered anaerobic ponds at the Churchill Abattoir is that when these temperature variances occur the anaerobic digestion process slows, treatment performance is reduced and biogas generation is dramatically affected, (see Chapter 4 for analysed results) (Stewart & Trangmar, 2008, p. 29).

Figure 4. Anaerobic pond cover made from HDPE at the Churchill Abattoir

3.5 Biogas handling

In order to control Greenhouse Gas emissions and to harness biogas, the wastewater treatment system must be controlled appropriately. The use of covered anaerobic ponds and utilising the collected biogas for electricity generation or other on-site use will reduce around 75% of the Greenhouse Gas impact of the methane entering the atmosphere from each anaerobic pond (Stewart & Trangmar, 2008, p. 25).

The biogas recovered from an anaerobic digester is approximately 60-80% methane with a heating value of about 19-23 MJ/m^3 (Geradi, 2003). When handling the biogas produced, Australian Gas Standards must be met for all collection systems, for the safety of the system as well as the safety of the operators. The correct valves and fittings must be used for safe operation. If storage of the biogas is required, compression of the biogas by specialised equipment, such as a compressor and pump, may be utilised. This will increase costs and will entail a permanent structure for the gas collection system. An appropriate area must be considered for this system to be placed, and it might be wise to minimise the distance from the ponds to this system so that there aren't any unnecessary energy input requirements for pumping the biogas into the collection and storage system.

3.6 Biogas potential for renewable energy

As it is today, the combustion of fossil fuels for power generation cannot precede indefinitely. The incentive to improve and utilise biogas as a renewable energy resource is steadily improving as a successful technology. Biogas produced during anaerobic digestion typically contains about 70% methane. This biogas is a very valuable resource and can be utilised in the offset part of energy requirements for in-plant use (Khnal, 2008, p. 267).

The feed characteristics influence the quantity and quality of biogas produced during anaerobic digestion. Methane generation can be estimated through several different methods from a waste stream during anaerobic digestion. Typical gas production rates for different substrates are shown in Table 2 (Khnal, 2008) below.

Table 2. Typical digester gas production rates

	Specific gas production per unit mass destroyed
Substrate	**m^3/kg**
Fats	1.2-1.6
Scum	0.9-1.0
Grease	1.1
Crude Fibres	0.8
Protein	0.7
Carbohydrates	0.7

3.6.1 Biogas utilisation as a fuel

A number of different factors influence the best use for biogas produced for particular circumstances. The amount of biogas produced, energy cost, plant's energy demand, and other incentives are just a few of these factors (Khnal, 2008, p. 279). The combustion in an engine and generator system to produce electrical power is one of the most common applications for the utilisation of biogas. With the rise in cost and erratic supply of unstable fossil fuels, incentives for enhanced biogas as a renewable energy resource has widespread.

Internal combustion engines or gas turbines that drive generators can be used to generate electricity from biogas at the Churchill Abattoir. Internal combustion engines are easily converted to burn biogas with some modifications of the fuel and ignition systems. Biogas-fuelled internal combustion engines are capable of converting about 35% of the biogas energy to electricity, with the remainder of the energy being converted into heat (Stewart & Trangmar, 2008, p. 33). Small gas turbines are also available for generating electricity using biogas as the fuel. The use of a gas turbine will lower nitrous oxide emissions compared to that of the use of an internal combustion engine, however the efficiency of a gas turbine is much lower than that of an internal combustion engine. The generators that are usually used for these applications are induction generators, since they are much cheaper and less sophisticated than synchronous generators.

Control systems are used to monitor sensors that indicate when a mechanical problem occurs (e.g. low oil level) and shut down the engine before it causes catastrophic failures. All control systems can be specifically designed to the appropriate requirements of a particular electrical generation system. Some of the heat energy from the engines exhaust and the engines cooling system can be recovered for heating the ponds or provide heat for other on-site purposes, where approximately 65% of the fuel energy is converted to heat. However, for anaerobic digestion with the use of covered ponds, it is not feasible to utilise this heat energy to increase the temperature of the digestion system, but to utilise it to heat water for cleaning of equipment at the abattoir or some other on-site purpose.

The generation of biogas using anaerobic digestion from the wastewater can benefit the Churchill abattoir by providing on-site energy by the utilisation of an internal combustion engine or gas turbine to produce electricity with the aid of a generator.

The electricity produced may be used to run pumps for the wastewater management system which will cut costs for electricity needs that are required for this system at this present time. If surplus electricity is being produced the power may be connected back to the abattoir to be used for heating or cooling purposes, used for powering electric motors for mechanical mixing of the ponds, or it may be fed into the national electricity grid.

If internal combustion engines or gas turbines are used for the generation of electricity, great concern must be taken for the composition of the biogas before it is utilised. If its composition shows high levels of impurity gases such as H_2S, it needs to go through certain processes to remove these corrosive and energy-absorbing gases. If not properly monitored, controlled and removed the H_2S will cause failure to all mechanical systems (valves, pipes, gauges, pumps, etc), and failure of an internal combustion engine or gas turbine will be very expensive.

Hydrogen sulphide and ammonia levels within the biogas will need to be reduced in order to prevent the risk of corrosion within the mechanical components within the electricity generation system and reduce the production of toxic compounds under certain conditions. When methane burns it forms carbon dioxide and water. However, if hydrogen sulphide is present it will oxygenate to form water and sulphur dioxide and then forming sulphuric acid when nickel and heat are present. This is also the case for the conversion of ammonia gas to nitrogen and water (Clayton, Leaney, Andy, & Robbins, 2009).

Another option for the utilisation of the biogas may be to use direct flaring of the biogas to reduce the CH_4 released into the atmosphere, which will help to reduce GHGs and protect the environment. This may earn carbon credits from the Queensland government as well.

3.7 Biogas impurities

It is essential for gas cleaning to take place for the use of biogas as a fuel. It is most important to reduce condensation, lower hydrogen sulphide levels, and remove siloxanes to ensure that the gas will meet the quality requirements for the operating equipment, in order to maintain the life of the equipment.

The existence of carbon dioxide in biogas is not considered to be a contaminant, although it does reduce energy in the biogas. Therefore the reduction of the carbon dioxide in the gas mixture helps to enrich the fuel value of the biogas.

Typically, moisture saturates biogas from anaerobic digesters at operating temperature. Hydrogen sulphide within the biogas will dissolve with any moisture that has condensed on the mechanical components, and increased corrosion will result. H_2S will form sulphuric acid in the presence of moisture, which becomes highly corrosive to pipelines, gas utilisation equipment, and gas storage tanks. This shortens the life of the operating components within the wastewater treatment system. Moisture can be removed by cooling the gas, but this requires an energy input which lowers the efficiency of the system.

Siloxanes are contaminates that must be taken into consideration for the use of biogas as an energy source. Siloxanes are organic polymers that are used in a variety of different areas, including commercial, personal care, industrial, medicinal, and food applications. An abrasive solid build-up takes place on moving parts or heat exchange surfaces when oxidation of the volatile compounds found in these sources of siloxanes are released as gas during the digestion processes. This results in an increased wear rate, causing damage to engines, turbines and fuels cells, and a reduction of heat transfer efficiency (Khnal, 2008, p. 274). Activated carbon or graphite media filters, as well as refrigerant dryers are used to remove siloxanes from the biogas.

3.7.1 Biogas scrubbing methods

The removal of contaminants from the biogas produced is essential, because it contains hydrogen sulphide and ammonia which are acidic gases that will cause severe corrosion to all mechanical components. Also it is necessary to remove CO_2 from the biogas so that the energy density per unit volume is increased and efficiencies for electricity generation are enhanced. Some methods that are being used in the petro-chemical industry today to remove CO_2 are outlined below.

The physical or chemical absorption method is the most cost effective and simplest procedures, involving pressurised water as an absorbent. The process involves the biogas to be compressed, where it is fed into a packed bed column from the bottom. Here, pressurised water is sprayed from the top and the counter-current absorption process occurs (Kapdi, Vijay, Rajesh, & Prasad, 2004, p. 3). This method allows the CO_2 and H_2S to be dissolved in the water. Chemical absorption requires a high energy input, where the formation of reversible chemical bonds between the solute and solvent is utilised, through regeneration of the solvent, resulting in breaking the bonds.

Adsorption methods are very effective in removing CO_2, H_2S, moisture and other impurities, within the gas stream. The method is simple in design and easy to operate, however high temperatures and pressures are required for the process, where solute in the gas stream is transferred to the surface of a solid material. Other methods such as membrane separation, cryogenic separation and chemical conversion prove to be effective ways to remove contaminates from biogas, however they are complex in design and require high input energy and have not yet been successfully proven (Kapdi, Vijay, Rajesh, & Prasad, 2004, p. 5).

Removing H_2S by dry oxidation can be performed by two different methods. By introducing a small amount of oxygen (2-6%) into the biogas system, sulphide in the biogas is oxidised into sulphur and the H_2S concentration is lowered. This method is simple and cost effective since there are no chemicals or specialised equipment required. Adsorption using iron oxide is also used to remove H_2S, where the biogas passes through iron oxide pellets. This method is simple but very sensitive to high water content in biogas and the dust packing contains a toxic component (Kapdi, Vijay, Rajesh, & Prasad, 2004, pp. 5-6).

It is found that water scrubbing is the most simple and the least expensive method for removal of CO_2 and H_2S concentrations in biogas. This scrubbing method is recommended for the pre-treatment of the biogas produced before being utilised in an electrical energy generation system used for the Churchill Abattoir.

3.8 Summary

The wastewater treatment system at the Churchill Abattoir was discussed, and the composition of the raw effluent entering the anaerobic ponds was outlined. The anaerobic pond cover design was explained and biogas handling options for the utilisation as of the biogas as a fuel was summarised. Following this, the methods for biogas scrubbing of impurities were described.

Chapter 4 Simulation, Results and Analysis

4.1 Introduction

Simulations were run using the BioWin software to provide accurate estimations for the potential biogas generation and the biogas quality. This chapter deals with the results obtained from the BioWin software that was used to simulate the biogas production and effluent quality of the wastewater treatment system used at the Churchill Abattoir. Graphs are presented for the expectation of the methane and carbon dioxide content within the biogas and gas flow rate for each pond over 365 days, as well as the quality of the effluent.

4.2 Background

Dynamic wastewater treatment modelling was utilised to define and analyse the behaviour of the wastewater treatment system used at the Churchill Abattoir. A Microsoft Windows-based simulator titled *'BioWin,'* created by EnviroSim Associated LTD, was used to estimate potential biogas production and effluent quality based on data provided by the Churchill Abattoir. Modelling biological processes in BioWin gives an advantage through that BioWin models merge both activated sludge and anaerobic biological processes and it integrates pH and chemical phosphorous precipitation processes. The BioWin simulator suite includes a steady state module and an interactive dynamic simulator. The steady state module is used for analysing systems based on constant influent loading and/or flow weighted averages of time-varying inputs. The interactive dynamic simulator gives the user the ability to operate and manipulate the treatment system whilst the simulation is running, ideal for analysing system response when subject to time-varying inputs or changes in operating strategy.

4.3 Sampled data

Some field test data was supplied by the Churchill Abattoir, which was utilised for the BioWin modelling and simulation. The data provided had been sampled and tested over the past several years (from 2004-2010). An average of this data has been tabulated below.

Table 3. Average test data provided by the Churchill Abattoir

	Average Test Results				
	Raw	**Pond 1 out**	**Pond 2 out**	**Pond 3 out**	**Pond 4 out & Irrigator**
COD	-	-	-	-	-
BOD	2799	250	149	136	108
TSS	2473	429	258	257	298
N	499	618	494	452	180
P	79	96	87	88	61
PH	6.91	7.22	7.66	7.76	8.12
DO	4.50	2.05	3.67	4.89	5.89
Oils/Greases	1242	91	17	18	37

This data was sampled from the old wastewater treatment system. However, the values of the raw influent are still viable to use as an input in the BioWin software. All other values from each pond have been used as a general expectancy figure for justification of obtaining accurate results.

4.4 BioWin modelling and simulation

This software will give a good indication of what to expect to see from the covered anaerobic ponds' performance, with regards to the biogas production and effluent quality for agricultural or other purposes. The setup of the modelling was implemented to integrate the field test data into the BioWin software. The average values for the raw wastewater were used as the influent flow into the model. The figure below shows the flow chart that was used to simulate the five covered anaerobic ponds used at the Churchill Abattoir.

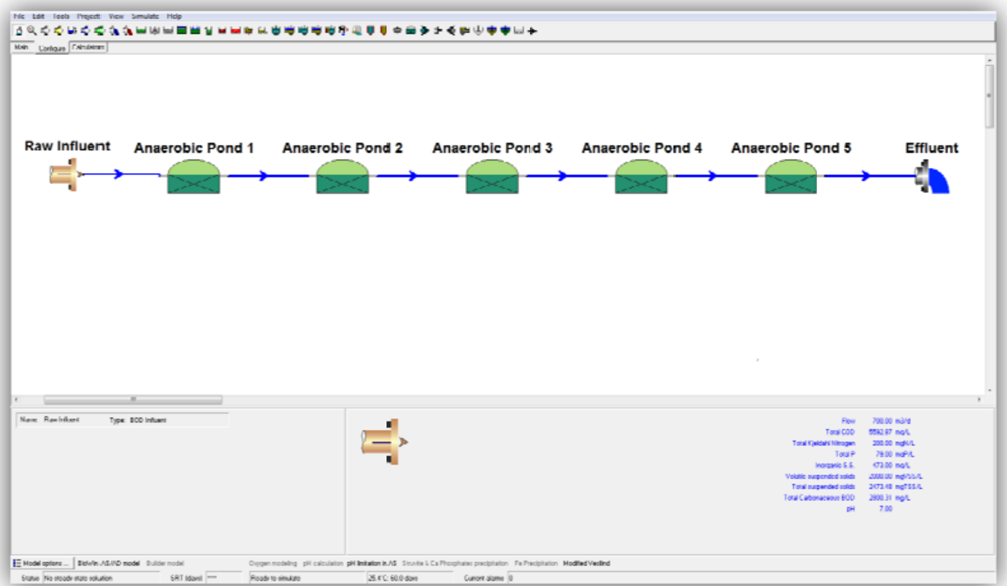

Figure 5. BioWin software for the five covered anaerobic ponds

4.5 Input data

In order to simulate the biological processes that occur during anaerobic digestion, certain input variables are set. The Raw Influent block determines the constant values that are introduced into the wastewater system. The input variables used are tabulated below.

Table 4. Raw influent inputs (provided by the Churchill Abattoir)

Elements	
Total Carbonaceous BOD [mg/L]	2800
Total COD [mg/L]	5593
Total suspended solids [mgTSS/L]	2473
Total Kjeldahl Nitrogen [mgN/L]	200
Volatile suspended solids [mgVSS/L]	2000
Volatile fatty acids [mg/L]	134.23
pH	6.91
Alkalinity [mmol/L]	6.00
Total N [mgN/L]	700
Total P [mgP/L]	79

The values that have been used for the input into the model have been taken from the average values that were provided by the Churchill Abattoir. These values were sampled and averaged over the last several years. For each of the Anaerobic Pond blocks, data was edited for the volume, depth and temperature. Each pond has a volume of approximately 4000m^3 with a depth of about 5m (20mx40mx5m). Data was taken from the Australian Government Bureau of Meteorology for average monthly temperatures for the past 30 years at the Amberley Amo site (BOM, 2010), located 5.3km from Ipswich. The statistics are shown in the table below.

Table 5. Monthly climate statistics from the Amberley Amo site

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean maximum temperature (°C)	31.4	30.7	29.6	27.3	24.4	21.8	21.5	23.1	26.4	28.2	29.3	30.9	27.0
Mean minimum temperature (°C)	19.4	19.2	17.1	13.7	10.0	6.4	5.0	5.6	9.2	12.9	15.9	18.2	12.7

These values show average maximum and minimum monthly temperatures. In order to estimate the maximum potential of biogas production from this model, the statistics for the maximum temperatures were edited into each Anaerobic Pond block for a period of 1 year (365 days). When the simulation is run for 365 days, the temperature is scheduled to change accordingly, which enhances the accuracy of the solution. This will give a good idea of the expected biogas production over the hottest months of summer and the warmest temperatures for the months over the winter season. Each Anaerobic Pond block will output values for Hydraulic Resistance Time, Volatile Suspended Solids, Total Suspended Solids, volatile fatty acids, total COD, Ammonia N, pH, Gas Flow rate (dry), Methane content, and Volatile Suspended Solids destruction. These constant values were obtained after a steady-state simulation and are presented in a table in Appendix D. The Effluent block will output values for wastewater flow, Ammonia N, Nitrate N, Nitrite N, Filtered TKN, total N, total P, Total Suspended Solids, total COD, Total Carbonaceous BOD, and pH.

4.6 BioWin simulation results

After the input variables were entered into the Influent block and the scheduled temperatures were edited for each of the Anaerobic Pond blocks, the Dynamic Simulation was run. The combined methane content for each anaerobic pond for the 1 year period is shown in the figure below. From this graph it is seen how each pond is compared through the hot months over the summer and the colder temperatures through the winter months. Pond 1 shows the most variance to methane production compared to the other ponds. Pond 2 also shows a large deviation from the other ponds. It is explained in further sections the more detailed reasons for such differences between each pond.

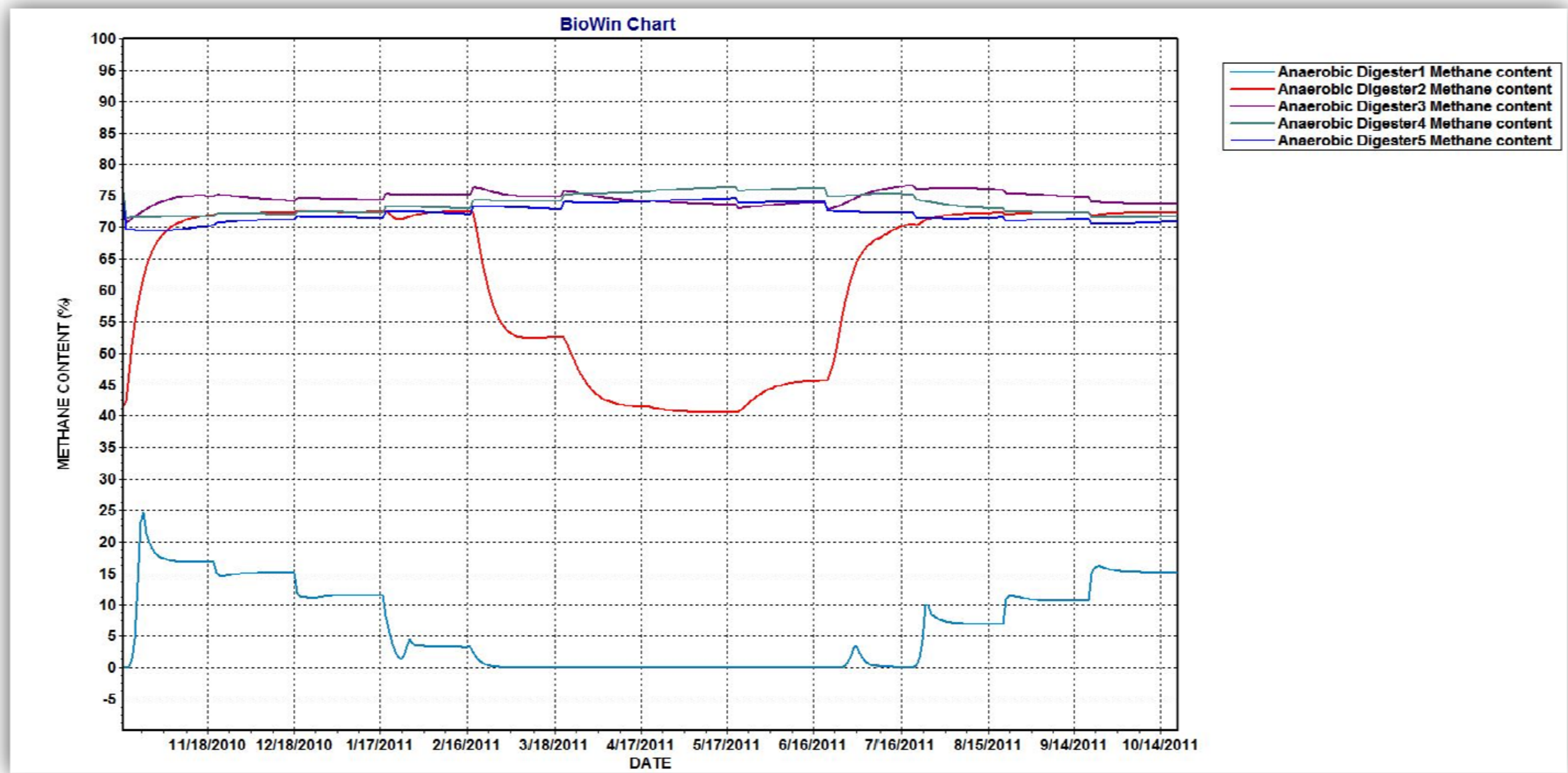

Figure 6. Methane Content from the system over 1 year

4.6.1 BioWin results from Pond 1

It is seen in the left graph in Figure 7 below, that for Pond 1, the methane content is quite low, where during a period from the third month of the year (March) to the seventh month (July), the percentage of methane within the biogas is zero. It is also seen that the carbon dioxide content varies between about 19%-24%. The graph on the right shows the production of overall biogas, measured as gas flow rate (dry) (m^3/day). The production of biogas is also affected during the middle of the year, which shows that consistent results have been obtained for the first pond. The reason that the production of total biogas and the percentage of methane within the biogas are affected so much is because of the colder months through the middle of the year. The temperature is one of the most influential parameters for the production and quality of the biogas, during anaerobic digestion processes.

Also, another important parameter that has affected the performance of the first pond is that the Hydraulic Retention Time is too low. The time that the wastewater remains in the pond is only 5.7 days, before it is then gravity fed to Pond 2. This needs to be increased to at least 20 days in order to achieve optimal bacterial activity within the wastewater. If the wastewater remains in the pond for a longer period of time, it can break down the organic material sufficiently, which will avoid short circuiting and allow for pond volume reduction. This will also affect the start-up time for the system to reach its full operating potential.

The results show that the methane produced is very low with large variations ranging from a peak maximum of approximately 25% and a minimum of 0% content. The overall biogas produced also shows similar variations as to the methane production, where a maximum of about 825m^3/day is being produced during start-up, with a minimum of 340m^3/day during the colder months of the year and settling at just under 600m^3/day.

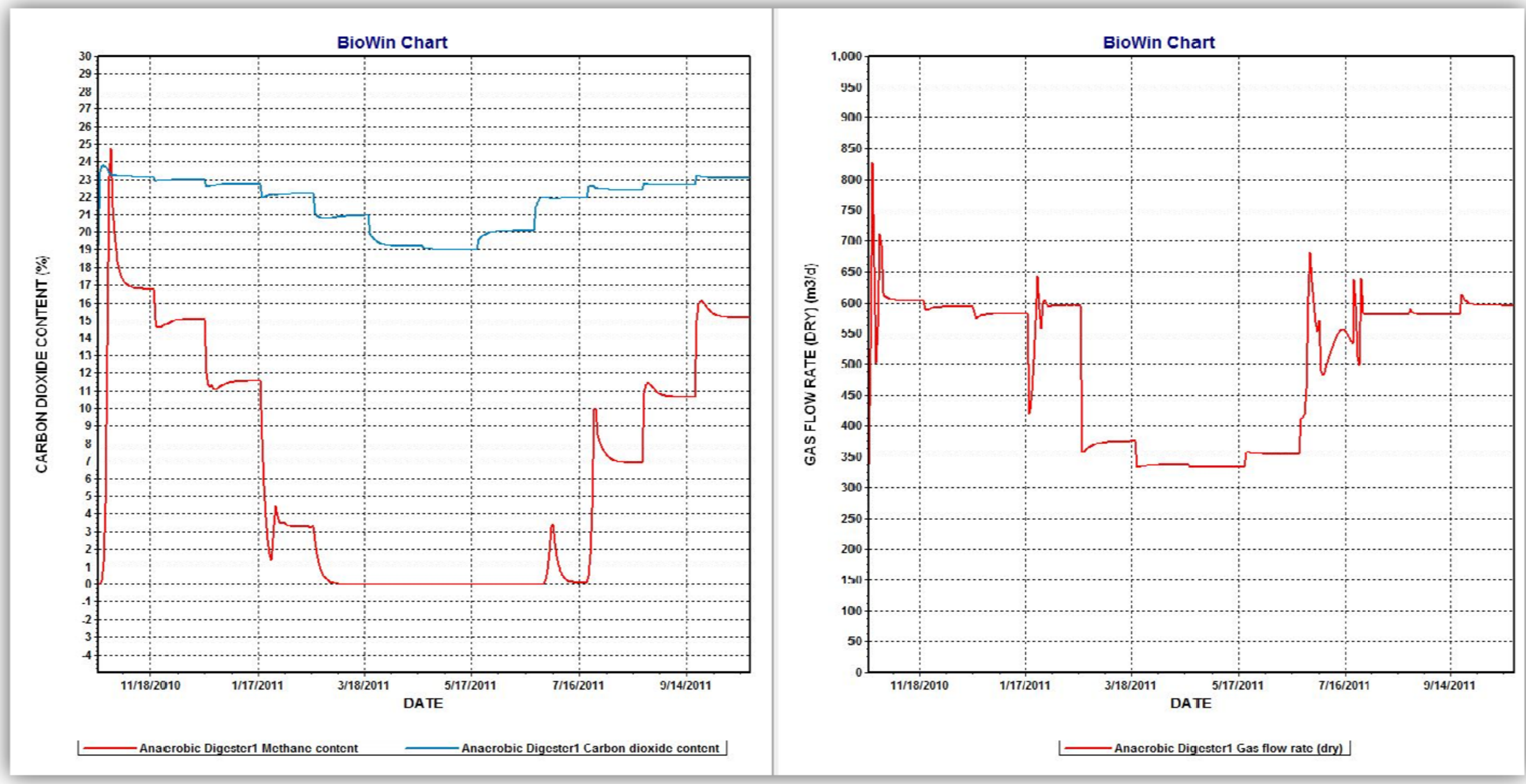

Figure 7. Methane, Carbon Dioxide and Gas Flow Rate of Pond 1 over 1 year

4.6.2 BioWin results from Pond 2

The figure below shows the methane and carbon dioxide percentage within the biogas produced (left graph). The methane content increases up to about 72% during start-up and then, as expected, decreases rapidly at March. The content increases again back up to a steady 72% at about the seventh month (July). The lowest production of methane occurs for the four month period that the temperature is at its lowest, where the biogas has a methane content of about 40%. This distribution is caused by the activated sludge that has entered the second pond from the first pond. The microbiological processes that occur during anaerobic digestion are already in operation of breaking down the organic material, thus producing a higher content of methane in this pond than the first pond. The carbon dioxide content remains almost constant throughout the year, where it is stable at about 23%, which is expected for this system.

The gas flow rate (right graph) shows the production of biogas for Pond 2 over the year. Initially, the gas flow rate is high but rapidly drops off during start-up and settles between 150-170m^3/day from November to March. After this, the gas flow rate increases every month up to a maximum of about 245m^3/day, until July where the production rate drops to a minimum of about 138m^3/day. The flow rate then begins to stabilise as it rises up over 170m^3/day. It is expected that the gas flow rate for this pond and the following ponds to be producing biogas at a rate greater than 100m^3/day. This is because the wastewater in this pond and in the following ponds are being adequately digested (BOD removal), so less biogas is able to be produced as the organic material is biodegraded, compared to the first pond where it was producing almost three times the volume of biogas per day. The biogas in the first pond will have a lower energy density per unit volume compared to the second pond, due to the lower amount of methane within the biogas.

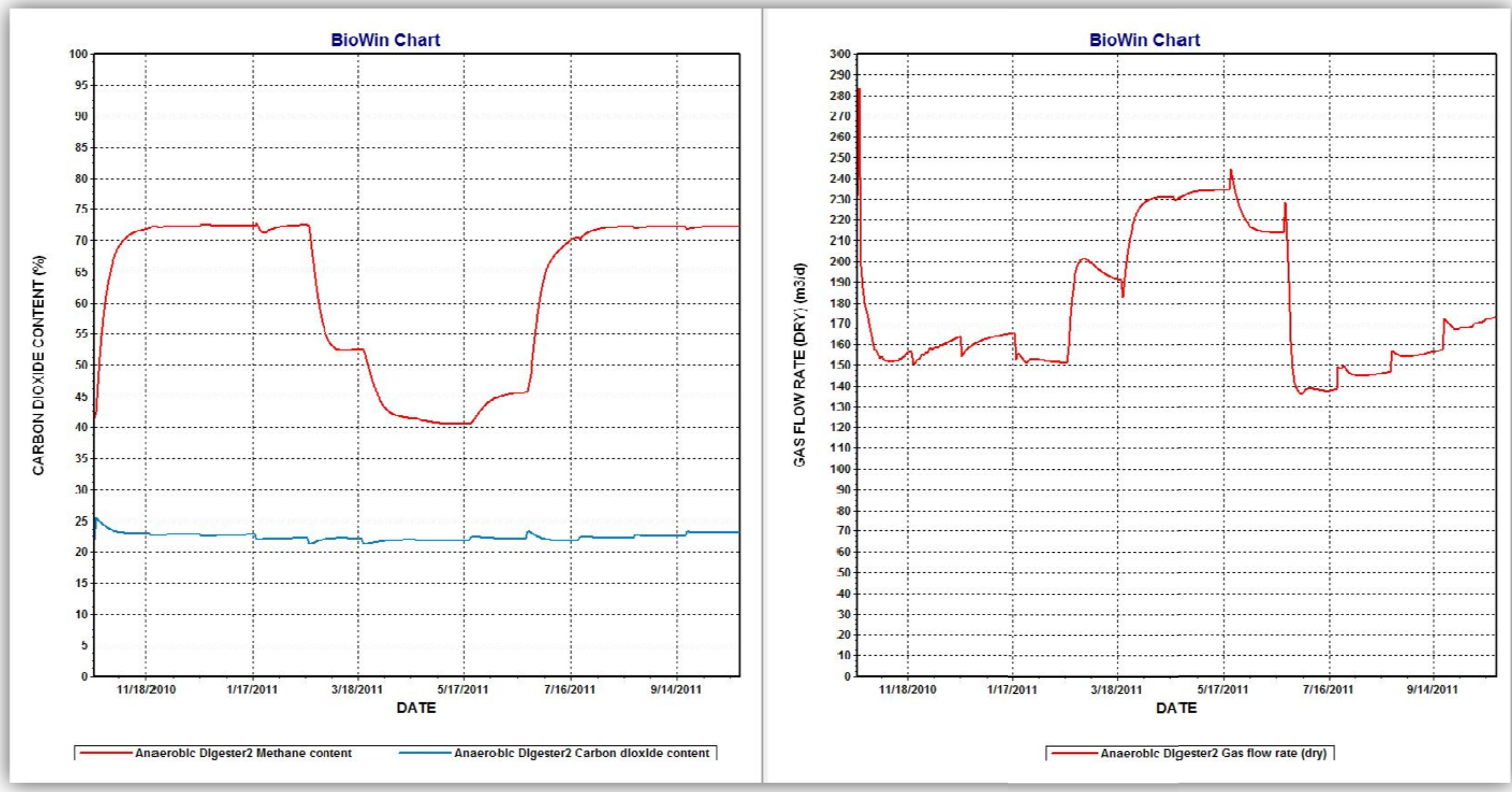

Figure 8. Methane, Carbon Dioxide and Gas Flow Rate of Pond 2 over 1 year

4.6.3 BioWin results from Pond 3

The methane and carbon dioxide percentage for the third pond are seen to be quite consistent as shown in Figure 9 below. The methane production is stable at about 75% and the carbon dioxide is stable at about 24%. The contents within the biogas are very steady throughout the year. It shows that the biogas quality is at a reliable state and that this pond will provide a consistent supply of quality biogas throughout the year.

The gas flow rate from this pond is not as consistent as its contents, however. During start-up the biogas production increases up to almost 290m^3/day over three months, then reduces down to eventually reaching its minimum flow rate of about 100m^3/day over the colder months of the year. This is as expected over the middle of the year, as is the increase of biogas production back to over 300m^3/day when the temperature has again increased for the summer period.

This pond is showing its full potential of biogas production and quality. However, if the hydraulic retention time is increased this pond will be able to produce a higher flow rate of biogas. The following pond is expected to have an equal or higher biogas production rate than Pond 3, since the wastewater will have been in the whole treatment system for at least 20 days, which is the recommended time (Green, p. 60) for the wastewater to remain under anaerobic conditions for optimum performance.

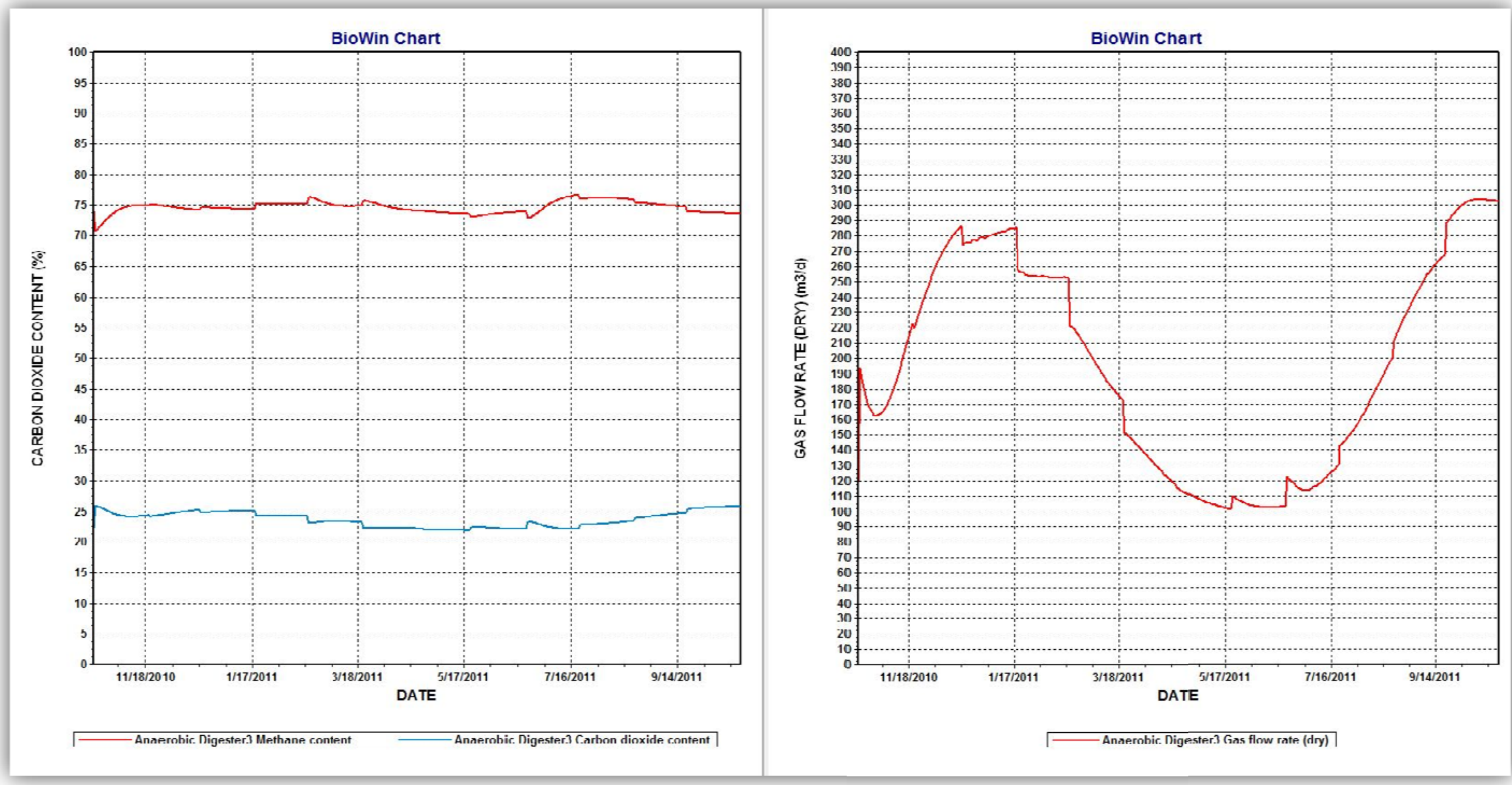

Figure 9. Methane, Carbon Dioxide and Gas Flow Rate of Pond 3 over 1 year

4.6.4 BioWin results from Pond 4

From the results obtained in Figure 10 below, Pond 4 produces the most consistent quality and supply of biogas throughout the year. The methane content is very stable over the 12 months, reaching a maximum of about 76% with steady production over 72%. The carbon dioxide content is also reasonably constant keeping between 24-27% all year. This quality of biogas would be ideal for all ponds to achieve, since it will provide a sufficient renewable energy resource all year.

The gas flow rate from the pond, justifies Pond 4 to have the best performance for the system. The biogas production reaches a maximum of over 360m^3/day and drops to its minimum rate of just under 160m^3/day during the colder climate from March through to July. Again, this is as expected for this time of the year under these conditions. The main reason that the biogas production rate is prominent over the other ponds is because of the time that the wastewater has been activated under anaerobic digestion conditions. The wastewater has been slowly digested through the treatment system and has reached Pond 4 where it has obtained its maximum potential for the system.

As seen for the fifth pond in Figure 11, the biogas production shows similar results to that of Pond 3.

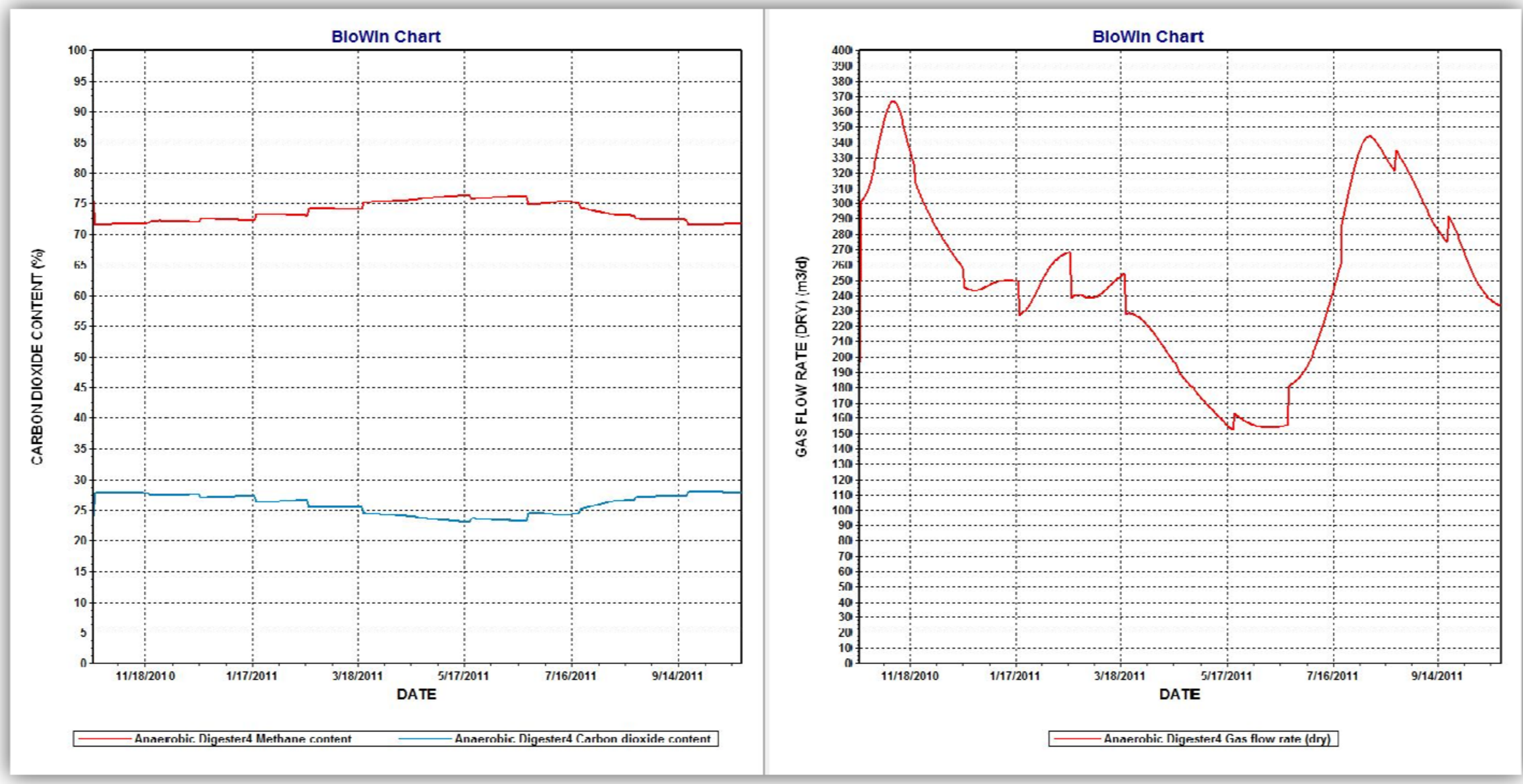

Figure 10. Methane, Carbon Dioxide and Gas Flow Rate of Pond 4 over 1 year

4.6.5 BioWin results from Pond 5

The results obtained for Pond 5 in Figure 11 below, show a consistent methane and carbon dioxide percentage within the biogas. The methane ranges between 70-75% and the carbon dioxide ranges between 25-30%. These values are normal and are to be expected. The temperature seems to have little effect on the amount of CH_4 and CO_2 being produced within the biogas over the year.

The graph of gas flow rate for the year shows that the production of biogas drops off rapidly to about 100m^3/day during start-up and then slowly increases up to its maximum of over 300m^3/day by July. After this the production of biogas decreases back to just over 100m^3/day over a period of about 4 months. From this it is seen that there is only a sufficient amount of biogas being produced for a period of about 7 months of the year, compared to the fourth pond which provides a minimum of over 150m^3/day for the whole year. This is an indication that the BOD removal is starting to reach its full potential. It means that the organic material within the wastewater is starting to be completely digested and so biogas production is slowed, although the quality of the biogas is still quite high. The biogas that is produced is still more than adequate to be utilised as a renewable energy resource.

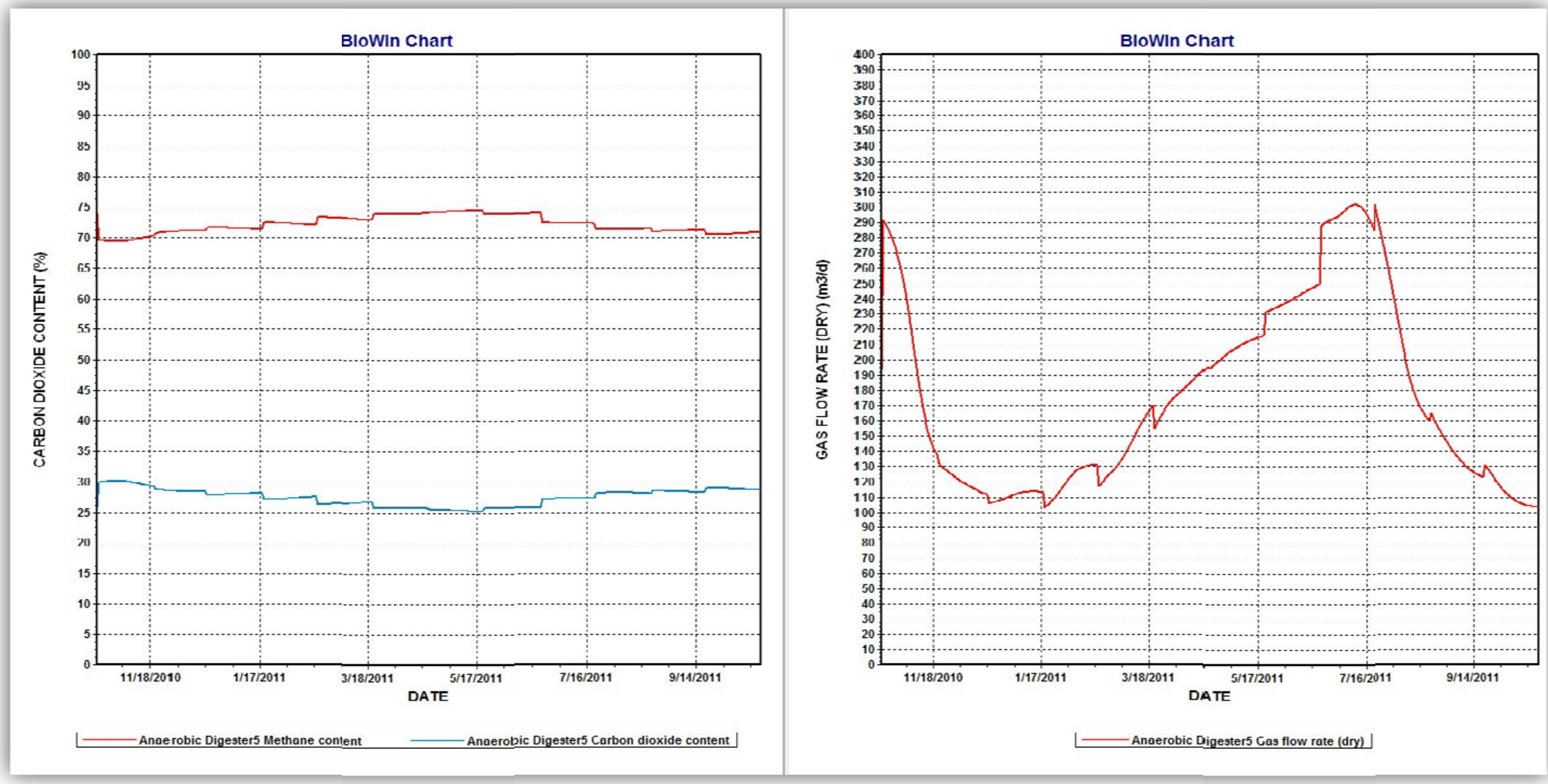

Figure 11. Methane, Carbon Dioxide and Gas Flow Rate of Pond 5 over 1 year

4.6.6 BioWin results of the effluent

The other important factor of the wastewater treatment system at the Churchill Abattoir is the effluent quality. It is essential for the effluent quality to be determined for the use of agricultural irrigation and washing purposes. The effluent quality must be considered for the issues relating to groundwater contamination, soil structure and land contamination for the surrounding region, and it must also be suitable for cleaning and washing purposes at the abattoir. The collection of data for the treatment system will require characterisation and continuous monitoring of parameters such as Total Suspended Solids, BOD, COD, pH, Total Kjeldahl Nitrogen and Ammonia N. Values for the parameters mentioned here are available for the effluent of this system but have not been presented in this section. See Appendix E for a chart taken over a 1 year period for these parameters.

These parameters will give a good indication of the type of application and the application rates that can be applied. From the results obtained in Figure 12, it is seen that the BOD removal is increased rapidly after start-up with a lowest value of BOD to be about 200mgTSS/L, before decreasing in removal rate up to a maximum of over 560mgTSS/L. This occurs during the colder months of the year, which is expected. The removal rate increases again as the temperature increases towards the summer season. This justifies the slower production rates of biogas through the middle of the year when the temperature is at its lowest. The BOD removal rate is at its minimum from March to July, thus affecting the production of biogas from the anaerobic ponds.

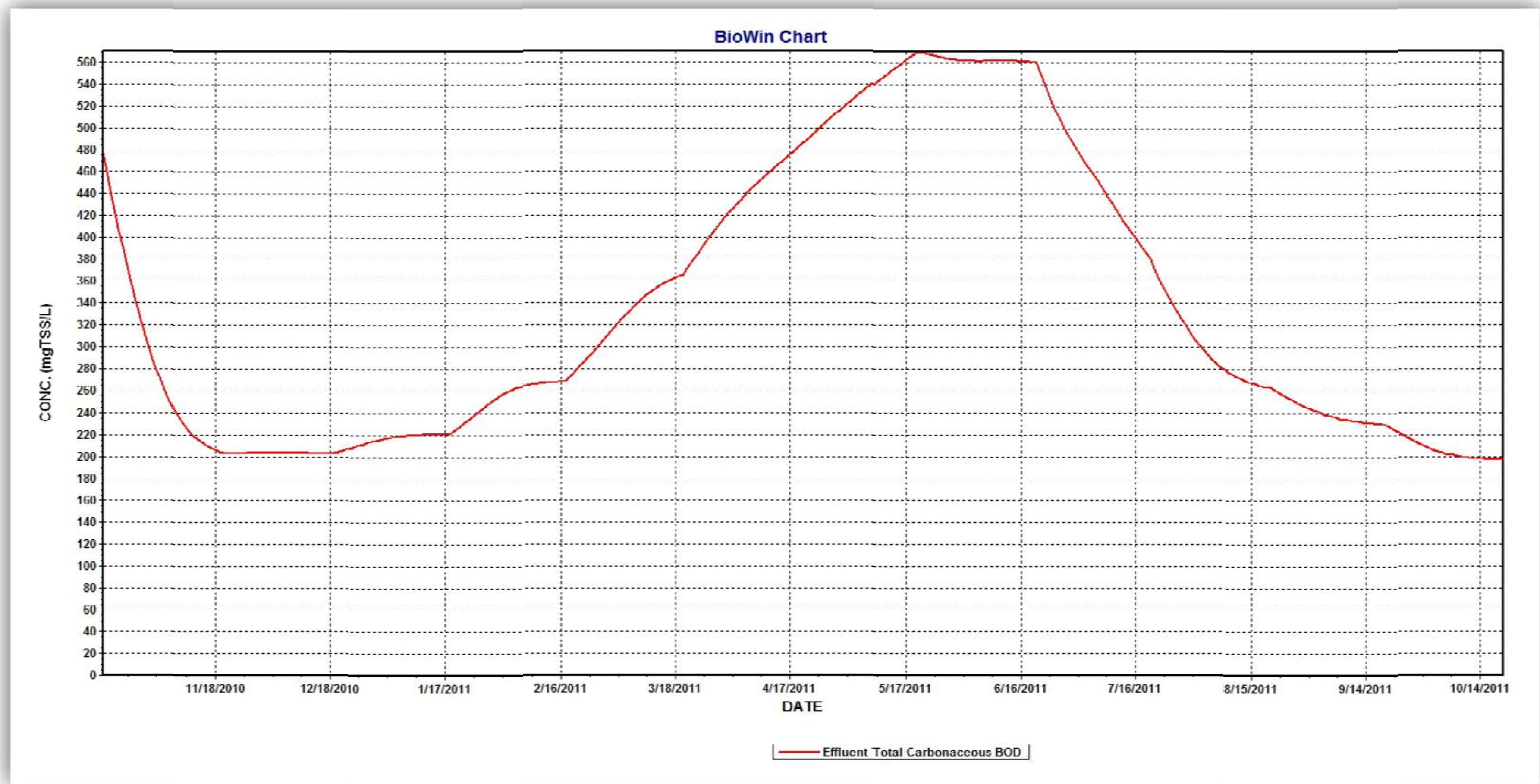

Figure 12. Total Carbonaceous BOD Effluent over 1 year

4.7 Conclusions

The expected methane and carbon dioxide percentages within the biogas produced were simulated, obtained and discussed for each anaerobic pond for the wastewater treatment system at the Churchill Abattoir. Also, the effluent quality was analysed from the results and discussed. It was found that one of the most dependant parameters for the production and quality of the biogas was the temperature change in the middle of the year from March to July. This was seen through the decrease in the BOD removal rate of the effluent, which affected the production rate of the biogas. The other dependant parameter was that the Hydraulic Retention Time was too short for all ponds and the appropriate microbial activity was unable to reach its full potential until the wastewater had been in the system for at least 20 days. Since the ponds are configured in series to each other, after the 5.7 days that the wastewater remains in the first pond, it is then fed to the consecutive pond (i.e. Pond 2), and so on. This design enhances mixing of the activated wastewater which increases the production and quality of the biogas. This also validates why Pond 4 shows the finest results in the system.

It is roughly estimated from the graphs of the gas flow rate for each pond, that the overall biogas production for 1 year is approximately 530,000m^3/year, which will avoid this exposure to the atmosphere.

Chapter 5 Discussion

5.1 Introduction

This chapter discusses the wastewater treatment system at the Churchill abattoir and summarises the sections covered for enhanced biogas production, biogas quality and effluent quality. Discussion is also made on future research required regarding the conclusions of this project.

5.2 Research and modelling limitations

The results of this research must be reviewed with consideration to the limitations of the project. Some of the limitations were unaccounted for, and therefore reflected on the overall result of the project.

The available literature for high strength abattoir wastewater treatment with the use of anaerobic ponds is very limited, especially for the red meat industry in Australia. This made research for this project a specified area that required great attention in order to obtain correct literature and data for the project.

Modelling and simulation of the system was achieved with the use of the BioWin software. This software was purchased as an academic version for educational purposes only. The results obtained from this software are not to be used for contract research or to provide consulting services.

The BioWin software does not have a function that allows for the hydraulic retention time to be changed. Instead, the volume of the pond must be increased to increase the retention time. This would then change the design of the pond and would give inaccurate results. This is a limitation within the setup of the software. Another limitation of the software was that it was only used for a very basic model and only the most fundamental parameters were set in the inputs of the software. Expert experience on the microbiology of high strength abattoir wastewater is required for higher accuracy results to be obtained, along with more detailed sampled data. This is to set all variables known for the particular wastewater so that the model can be simulated as close to the practical application as possible.

5.3 Future research

The future work that is required for the complete operation of the wastewater treatment system is the individual research and design on each pond configuration, the biogas collection system (anaerobic pond cover design), the biogas storage system, the biogas utilisation system, and the wastewater effluent utilisation system. All of these systems are a project in their own and are required for the Churchill Abattoir to reach its goals and full benefits from its wastewater treatment system.

The full commercial version of the BioWin system with the guidance of an expert in the microbiology of the high strength abattoir wastewater is required to achieve highly accurate results that are available to be released as reliable data for the project. This work will be used for future reference and future work to follow on, as to set criteria for all wastewater treatment processes for the Australian abattoir red meat industry.

5.4 Conclusions

This research provides an outline and guideline for what is to be expected of the wastewater treatment system used at the Churchill Abattoir. An accurate estimation of how much biogas production is to be expected from the covered anaerobic ponds was obtained and discussed along with the quality of the biogas. Recommendations were made for enhanced biogas production and quality.

The utilisation systems that were discussed in Chapter 3 for the biogas to be used as a renewable energy resource for the generation of electricity were considered, along with the environmental considerations involved.

The hypothesis was justified with the results obtained, that the temperature is one of the most dependant parameters for the biogas production and quality during anaerobic digestion processes. In order to maximise the biogas production and enhance the methane content within the biogas, the temperature must be kept at a constant in order to maintain optimum methanogenic bacterial activity. The pond design was considered in the BioWin software for the sizing and volumes of each anaerobic pond. This affected the hydraulic retention time, as well as the start-up time and biomass yield (biogas produced). The wastewater must remain within the complete system for a sufficient time in order to achieve its optimum performance.

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Appendices

Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENIGINEERING AND SURVEYING

ENG 4111/4112 Research Project

PROJECT SPECIFICATION

FOR:	The National Centre for Engineering in Agriculture (NCEA) to Meat and Livestock Australia (MLA)
TOPIC:	BIO-GAS GENERATION FROM AN ANAEROBIC POND "ABATTIOR"
SUPERVISOR:	DR. TALAL YUSAF
ENROLMENT:	ENG 4111 – S1, 2010 ENG 4112 – S2, 2010
PROJECT AIM:	This project aims to provide sufficient literature and research on the current wastewater treatment system used at the Churchill Abattoir, (located in the South East Queensland Brisbane region of Ipswich). It is proposed to give a guideline of the technology, in order to make recommendations to improve the system, by providing estimations of potential biogas production and an indication of the expected effluent quality for suitable effluent disposal processes. The feasibility of bio-energy production from the covered anaerobic ponds was determined and sufficient technical research and information on the performance of the technology is to be provided for the meat and livestock industry via Meat and Livestock Australia.
SPONSORSHIP:	Churchill Abattoir

PROGRAMME:

1. Research the background information where a detailed review of available literature in the use of covered anaerobic ponds will be conducted to identify the best design features and management practices for treatment of high strength abattoir wastewater.

2. Guidelines will be informed through on site measurement and sampling conducted at Churchill Abattoirs, as appropriate.
3. The ponds will be instrumented to monitor performance including feeding rate, decomposition rate, BOD, temperature, microbial activity and waste composition of the anaerobic process.
4. Measurements of the following effluent characteristics in the inflow and outflow samples:
    - COD, BOD_5, TSS, TKN, NH_3-N, Oil & Grease, EC by NATA-registered or equivalent laboratory approved by MLA;
    -
    - pH, temperature, measured with suitably calibrated instruments in the field
    - volatile fatty acid (as mg/L as acetic acid); total alkalinity (as mg $CaCO_3$/L) in outflow samples only
5. Measurement of biogas flows (m^3/day) during the weeks of biogas sampling
6. Maintenance of the sampling program until the COD removal achieves a minimum of 80% COD removal in 2 consecutive samples

As time permits:

7. Investigate the use of covered anaerobic ponds for significant enhancements in odour control, intensification of the decomposition process and BOD removal, an increase in feed rate and the potential for capturing methane-rich gas as a fuel source for bio energy and the reduction in greenhouse gas emissions.
8. Testing of gas using an appropriate accredited and experienced laboratory for the following parameters:
    - CH_4, CO_2, moisture, H_2S, Total organic sulphur, ammonia-N, Volatile fatty acids
9. The project will conducted over a two year period.

AGREED ________________________(student) ____________________
(supervisor)

Date: 28 / 10 /2010 Date: 28 / 10 /2010

Examiner/Co-examiner:____.

Appendix B – Risk Assessment

Risk is usually related to individual risk or as communal risk with focus on public health and safety. Individual risk is seen as the risk of fatality to an individual when subject within the effect area of the hazardous incident. When a hazardous incident involves the fatality to a group of people, communal risk is assessed for the effect zone.

A risk assessment associated with the operation of the wastewater treatment system at the Churchill Abattoir has been evaluated with respect to risk during the execution of the project as well as the risk beyond the completion of the project.

Risk = Exposure * Consequence

The significance of risk (for each hazard) goes beyond the likelihood (probability) of occurrence. The risk factors (Table 6) of the operation of the anaerobic ponds operation are assessed using the exposure and consequence ratings presented.

Table 6. Risk assessment with respect to the exposure and consequences concerned

Risk factor	Exposure	Consequence
1	Very rarely (once per year or less)	Very minor (no measurable operational impact)
2	Rarely (a few times per year)	Minor equipment/component damage
3	Occasionally (occurs once or twice per month)	Serious destruction of equipment
4	Regularly (occurs weekly)	Major destruction of equipment. Minor injury/ illness
5	Frequently (occurs daily)	High impact across critical operational functions. Major injury/illness
6	Continuously	Catastrophic destruction. Possible death

Operational risks

Feedstock

The primary composition of biogas is methane and carbon dioxide, with traces of gas impurities such as ammonia N, nitrogen and hydrogen sulphide. These impurity gases may arise during biogas production. High exposure to these gases may result in illness or death (East Habour Management Services, 2004, p. 42). Therefore the influent substrate processing for biogas production is the first major risk consideration (East Habour Management Services, 2004, p. 41). The experience of the workers and good practice will determine the health and safety aspects of successful operation.

Probability = 3, Consequence = 4

Substrate supply

The supply of the substrate from the abattoir must be constant in order to maintain consistent operational conditions. Any variations in the loading rate may cause affect to the performance of the system, affecting the biogas production.

Probability = 2, Consequence = 2

Contamination of substrate

Contamination of the substrate through the transportation through vessels, as well as pesticides and chemicals may also heavily reduce biogas production.

Probability = 3, Consequence = 3

Wastewater storage

The storage of the wastewater must be processed as soon as possible in order to prevent aeration which reduces biogas yield. It also eliminates the potential of attracting parasites and insects, which will contaminate the substrate.

Probability = 4, Consequence = 2

Anaerobic considerations

During digestion processes, the anaerobic considerations are very important aspects to be taken. Any major change in temperature, alkalinity or pH will determine the performance of the anaerobic digestion process. It is very important to keep constant conditions within the system to achieve maximum biogas production.

Probability = 3, Consequence = 2

Biogas storage

Digester operations are usually safe, however incidents may occur during biogas processing operations. Major injury or even death may occur in the case of an explosion of the biogas, due to biogas leakage. This is where the storage of the biogas is very important and Australian Gas Standards and codes are considered.

Probability = 1, Consequence = 6

Biogas use

In some cases the biogas produced is used in the digestion process for heating applications, therefore the Australian Gas Standards and codes are considered with the combustion of gas to produce the heat.

Probability = 1, Consequence = 6

Effluent use

The effluent may be used in fertilisers for agricultural purposes. A build up of sludge and scum extracted from the ponds may also be used for humus land applications.

Probability = 1, Consequence = 2

Execution risks

Field testing

On-site measurements will be taken with respect to the monitored performance of anaerobic ponds including feeding rate, decomposition rate, BOD, temperature, microbial activity and waste composition of the anaerobic process. The on-site testing requires the correct equipment and instruments, as well as personal safety equipment and the correct workplace safety procedures to take place.

Probability = 1, Consequence = 2

Biophysical environment

The locations of the ponds are on elevated ground and are unlikely to be affected by flash flooding caused by a storm. There is a potential for the ponds to leak and contaminate the ground water and contaminate waterways close to the location of the ponds. The biogas produced is non-toxic and is not considered to be harmful to the flora and fauna in the area (Cheung, 2009, p. 58).

Probability = 1, Consequence = 2

Recommendations

A list of recommendations is provided to improve design and ensure a safe biogas recovery system.

- The installation of gas detection meters to alarm leaks with potential for explosion
- Fire break around the perimeter of the ponds to prevent explosions of the covered ponds from fires
- Provide pressure relief points on the pond covers

Conclusions

A preliminary risk assessment for the Churchill Abattoir biogas recovery system was completed. The purpose of the project is to improve the environmental performance of the wastewater management system, by reducing the Greenhouse Gas emissions released into the atmosphere by the digestion processes of wastewater treatment from the abattoir. In doing so, offensive odour is controlled. The results of the risk assessment have been summarised in Table 7 below. The rankings are in respect to the operational risks and the execution risks.

Table 7. Summary of risk assessment

Operational risks	Probability	Consequence	Risk factor
Feedstock	3	4	12
Substrate supply	2	2	4
Contamination of substrate	3	3	9
Substrate storage	4	2	8
Anaerobic considerations	3	2	6
Biogas storage	1	6	6
Biogas use	1	6	6
Output substrate use	1	2	2
Execution risks	**Probability**	**Consequence**	**Risk factor**
Field testing	1	2	2
Biophysical environment	1	2	2

The feedstock is the most important consideration of the operational risks, which requires careful attention to ensure successful operation of biogas production.

Appendix C – BioWin Report

BioWin user and configuration data

Project details

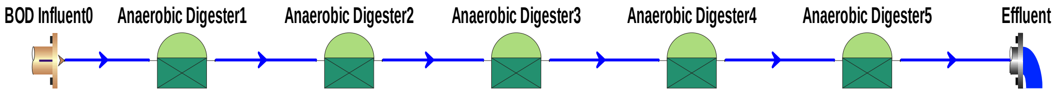
Project name: Churchill Abattoir wastewater treatment system

Plant name: Churchill Abattoir **User name:** Robert Di Bella

Created: 10/20/2010 **Saved:** 10/25/2010

Average Temperature: 27.0

Flow sheet



Configuration information for all Anaerobic Digester units

Physical data

Element name	Volume [m3]	Area [m2]	Depth [m]	Head space volume
Anaerobic Digester1	4000.0000	800.0000	5.000	1000.0
Anaerobic Digester2	4000.0000	800.0000	5.000	1000.0
Anaerobic Digester3	4000.0000	800.0000	5.000	1000.0
Anaerobic Digester4	4000.0000	800.0000	5.000	1000.0
Anaerobic Digester5	4000.0000	800.0000	5.000	1000.0

Operating data Average (flow/time weighted as required)

Element name	Pressure [kPa]	pH
Anaerobic Digester1	103.0	-
Anaerobic Digester2	103.0	-
Anaerobic Digester3	103.0	-
Anaerobic Digester4	103.0	-
Anaerobic Digester5	103.0	-

Element name	Average Temperature
Anaerobic Digester1	27.0
Anaerobic Digester2	27.0
Anaerobic Digester3	27.0
Anaerobic Digester4	27.0
Anaerobic Digester5	27.0

Configuration information for all BOD Influent units

Operating data Average (flow/time weighted as required)

Element name	BOD Influent0
Flow	700
Total Carbonaceous BOD mgBOD/L	2800.00
Volatile suspended solids mgVSS/L	2000.00
Total suspended solids mgTSS/L	2473.00
Total Kjeldahl Nitrogen mgN/L	200.00
Total P mgP/L	79.00
Nitrate N mgN/L	500.00
pH	6.91
Alkalinity mmol/L	6.00
Calcium mg/L	80.00
Magnesium mg/L	15.00
Dissolved oxygen mg/L	4.50

Element name	BOD Influent0
Fbs - Readily biodegradable (including Acetate) [gCOD/g of total COD]	0.1600
Fac - Acetate [gCOD/g of readily biodegradable COD]	0.1500
Fxsp - Non-colloidal slowly biodegradable [gCOD/g of slowly degradable COD]	0.6693
Fus - Unbiodegradable soluble [gCOD/g of total COD]	0.0500
Fup - Unbiodegradable particulate [gCOD/g of total COD]	0.1300
Fna - Ammonia [gNH3-N/gTKN]	0.6600
Fnox - Particulate organic nitrogen [gN/g Organic N]	0.5000
Fnus - Soluble unbiodegradable TKN [gN/gTKN]	0.0200
FupN - N:COD ratio for unbiodegradable part. COD [gN/gCOD]	0.0350
Fpo4 - Phosphate [gPO4-P/gTP]	0.5000
FupP - P:COD ratio for unbiodegradable part. COD [gP/gCOD]	0.0110
FZbh - Non-poly-P heterotrophs [gCOD/g of total COD]	0.0001
FZbm - Anoxic methanol utilizers [gCOD/g of total COD]	0.0001
FZaob - Ammonia oxidizers [gCOD/g of total COD]	0.0001

FZnob - Nitrite oxidizers [gCOD/g of total COD]	0.0001
FZamob - Anaerobic ammonia oxidizers [gCOD/g of total COD]	0.0001
FZbp - PAOs [gCOD/g of total COD]	0.0001
FZbpa - Propionic acetogens [gCOD/g of total COD]	0.0001
FZbam - Acetoclastic methanogens [gCOD/g of total COD]	0.0001
FZbhm - H2-utilizing methanogens [gCOD/g of total COD]	0.0001

Global Parameters

AOB

Name	Default	Value	
Max. spec. growth rate [1/d]	0.90000	0.90000	1.0720
Substrate (NH4) half sat. [mgN/L]	0.70000	0.70000	1.0000
Aerobic decay rate [1/d]	0.17000	0.17000	1.0290
Anoxic/anaerobic decay rate [1/d]	0.08000	0.08000	1.0290
KiHNO2 [mmol/L]	0.00500	0.00500	1.0000

NOB

Name	Default	Value	
Max. spec. growth rate [1/d]	0.70000	0.70000	1.0600
Substrate (NO2) half sat. [mgN/L]	0.10000	0.10000	1.0000
Aerobic decay rate [1/d]	0.17000	0.17000	1.0290
Anoxic/anaerobic decay rate [1/d]	0.08000	0.08000	1.0290
KiNH3 [mmol/L]	0.07500	0.07500	1.0000

ANAMMOX

Name	Default	Value	
Max. spec. growth rate [1/d]	0.10000	0.10000	1.1000
Substrate (NH4) half sat. [mgN/L]	2.00000	2.00000	1.0000
Substrate (NO2) half sat. [mgN/L]	1.00000	1.00000	1.0000
Aerobic decay rate [1/d]	0.01900	0.01900	1.0290
Anoxic/anaerobic decay rate [1/d]	0.00950	0.00950	1.0290
Ki Nitrite [mgN/L]	1000.00000	1000.00000	1.0000
Nitrite sensitivity constant [L / (d mgN)]	0.01600	0.01600	1.0000

OHOs

Name	Default	Value	
Max. spec. growth rate [1/d]	3.20000	3.20000	1.0290
Substrate half sat. [mgCOD/L]	5.00000	5.00000	1.0000
Anoxic growth factor [-]	0.50000	0.50000	1.0000
Aerobic decay [1/d]	0.62000	0.62000	1.0290
Anoxic/anaerobic decay [1/d]	0.30000	0.30000	1.0290
Hydrolysis rate (AS) [1/d]	2.10000	2.10000	1.0290
Hydrolysis half sat. (AS) [-]	0.06000	0.06000	1.0000
Anoxic hydrolysis factor [-]	0.28000	0.28000	1.0000
Anaerobic hydrolysis factor [-]	0.50000	0.50000	1.0000
Adsorption rate of colloids [L/(mgCOD d)]	0.80000	0.80000	1.0290
Ammonification rate [L/(mgN d)]	0.04000	0.04000	1.0290
Assimilative nitrate/nitrite reduction rate [1/d]	0.50000	0.50000	1.0000
Fermentation rate [1/d]	3.20000	3.20000	1.0290
Fermentation half sat. [mgCOD/L]	5.00000	5.00000	1.0000
Anaerobic growth factor (AS) [-]	0.12500	0.12500	1.0000
Hydrolysis rate (AD) [1/d]	0.10000	0.10000	1.0500
Hydrolysis half sat. (AD) [mgCOD/L]	0.15000	0.15000	1.0000

Methylotrophs

Name	Default	Value	
Max. spec. growth rate of methanol utilizers [1/d]	1.30000	1.30000	1.0720
Methanol half sat. [mgCOD/L]	0.50000	0.50000	1.0000
Aerobic decay rate of methanol utilizers [1/d]	0.04000	0.04000	1.0290
Anoxic/anaerobic decay rate of methanol utilizers [1/d]	0.03000	0.03000	1.0290

PAOs

Name	Default	Value	
Max. spec. growth rate [1/d]	0.95000	0.95000	1.0000
Max. spec. growth rate, P-limited [1/d]	0.42000	0.42000	1.0000
Substrate half sat. [mgCOD(PHB)/mgCOD(Zbp)]	0.10000	0.10000	1.0000
Substrate half sat., P-limited [mgCOD(PHB)/mgCOD(Zbp)]	0.05000	0.05000	1.0000
Magnesium half sat. [mgMg/L]	0.10000	0.10000	1.0000
Cation half sat. [mmol/L]	0.10000	0.10000	1.0000
Calcium half sat. [mgCa/L]	0.10000	0.10000	1.0000
Aerobic decay rate [1/d]	0.10000	0.10000	1.0000
Anaerobic decay rate [1/d]	0.04000	0.04000	1.0000
Sequestration rate [1/d]	6.00000	6.00000	1.0000
Anoxic growth factor NO3 [-]	0.33000	0.33000	1.0000
Anoxic growth factor NO2 [-]	0.33000	0.33000	1.0000

Acetogens

Name	Default	Value	
Max. spec. growth rate [1/d]	0.25000	0.25000	1.0290
Substrate half sat. [mgCOD/L]	10.00000	10.00000	1.0000
Acetate inhibition [mgCOD/L]	10000.00000	10000.00000	1.0000
Decay rate [1/d]	0.05000	0.05000	1.0290
Aerobic decay rate [1/d]	0.52000	0.52000	1.0290

Methanogens

Name	Default	Value	
Acetoclastic Mu Max [1/d]	0.30000	0.30000	1.0290
H2-utilizing Mu Max [1/d]	1.40000	1.40000	1.0290
Acetoclastic Ks [mgCOD/L]	100.00000	100.00000	1.0000
Acetoclastic methanol Ks [mgCOD/L]	0.50000	0.50000	1.0000
H2-utilizing CO2 half sat. [mmol/L]	0.10000	0.10000	1.0000
H2-utilizing Ks [mgCOD/L]	0.10000	0.10000	1.0000
H2-utilizing methanol Ks [mgCOD/L]	0.50000	0.50000	1.0000
Acetoclastic propionic inhibition [mgCOD/L]	10000.00000	10000.00000	1.0000
Acetoclastic decay rate [1/d]	0.13000	0.13000	1.0290
Acetoclastic aerobic decay rate [1/d]	0.60000	0.60000	1.0290
H2-utilizing decay rate [1/d]	0.13000	0.13000	1.0290
H2-utilizing aerobic decay rate [1/d]	0.60000	0.60000	1.0290

pH

Name	Default	Value
Heterotrophs low pH limit [-]	4.00000	4.00000
Heterotrophs high pH limit [-]	10.00000	10.00000
Methanol utilizers low pH limit [-]	4.00000	4.00000
Methanol utilizers high pH limit [-]	10.00000	10.00000
Autotrophs low pH limit [-]	5.50000	5.50000
Autotrophs high pH limit [-]	9.50000	9.50000
PolyP heterotrophs low pH limit [-]	4.00000	4.00000

Poly P heterotrophs high pH limit [-]	10.00000	10.00000
Heterotrophs low pH limit (anaerobic) [-]	5.50000	5.50000
Heterotrophs high pH limit (anaerobic) [-]	8.50000	8.50000
Propionic acetogens low pH limit [-]	4.00000	4.00000
Propionic acetogens high pH limit [-]	10.00000	10.00000
Acetoclastic methanogens low pH limit [-]	5.00000	5.00000
Acetoclastic methanogens high pH limit [-]	9.00000	9.00000
H2-utilizing methanogens low pH limit [-]	5.00000	5.00000
H2-utilizing methanogens high pH limit [-]	9.00000	9.00000

Switches

Name	Default	Value
Heterotrophic DO half sat. [mgO2/L]	0.05000	0.05000
Aerobic denit. DO half sat. [mgO2/L]	0.05000	0.05000
Ammonia oxidizer DO half sat. [mgO2/L]	0.25000	0.25000
Nitrite oxidizer DO half sat. [mgO2/L]	0.50000	0.50000
Anaerobic ammonia oxidizer DO half sat. [mgO2/L]	0.01000	0.01000
Anoxic NO3 half sat. [mgN/L]	0.10000	0.10000
Anoxic NO2 half sat. (mgN/L)	0.01000	0.01000
NH3 nutrient half sat. [mgN/L]	1.0000E-4	1.0000E-4
PolyP half sat. [mgP/L]	0.01000	0.01000
VFA sequestration half sat. [mgCOD/L]	5.00000	5.00000
P uptake half sat. [mgP/L]	0.15000	0.15000
P nutrient half sat. [mgP/L]	0.00100	0.00100
Autotroph CO2 half sat. [mmol/L]	0.10000	0.10000
Heterotrophic Hydrogen half sat. [mgCOD/L]	1.00000	1.00000
Propionic acetogens Hydrogen half sat. [mgCOD/L]	5.00000	5.00000
Synthesis anion/cation half sat. [meq/L]	0.01000	0.01000

Common

Name	Default	Value
N in endogenous residue [mgN/mgCOD]	0.07000	0.07000
P in endogenous residue [mgP/mgCOD]	0.02200	0.02200
Endogenous residue COD:VSS ratio [mgCOD/mgVSS]	1.42000	1.42000
Particulate substrate COD:VSS ratio [mgCOD/mgVSS]	1.60000	1.60000
Particulate inert COD:VSS ratio [mgCOD/mgVSS]	1.60000	1.60000

AOB

Name	Default	Value
Yield [mgCOD/mgN]	0.15000	0.15000
N in biomass [mgN/mgCOD]	0.07000	0.07000
P in biomass [mgP/mgCOD]	0.02200	0.02200
Fraction to endogenous residue [-]	0.08000	0.08000
COD:VSS ratio [mgCOD/mgVSS]	1.42000	1.42000

NOB

Name	Default	Value
Yield [mgCOD/mgN]	0.09000	0.09000
N in biomass [mgN/mgCOD]	0.07000	0.07000
P in biomass [mgP/mgCOD]	0.02200	0.02200
Fraction to endogenous residue [-]	0.08000	0.08000
COD:VSS ratio [mgCOD/mgVSS]	1.42000	1.42000

ANAMMOX

Name	Default	Value
Yield [mgCOD/mgN]	0.11400	0.11400
Nitrate production [mgN/mgBiomassCOD]	2.28000	2.28000
N in biomass [mgN/mgCOD]	0.07000	0.07000
P in biomass [mgP/mgCOD]	0.02200	0.02200
Fraction to endogenous residue [-]	0.08000	0.08000
COD:VSS ratio [mgCOD/mgVSS]	1.42000	1.42000

OHOs

Name	Default	Value
Yield (aerobic) [-]	0.66600	0.66600
Yield (fermentation, low H2) [-]	0.10000	0.10000
Yield (fermentation, high H2) [-]	0.10000	0.10000
H2 yield (fermentation low H2) [-]	0.35000	0.35000
H2 yield (fermentation high H2) [-]	0	0
Propionate yield (fermentation, low H2) [-]	0	0
Propionate yield (fermentation, high H2) [-]	0.70000	0.70000
CO2 yield (fermentation, low H2) [-]	0.70000	0.70000
CO2 yield (fermentation, high H2) [-]	0	0
N in biomass [mgN/mgCOD]	0.07000	0.07000
P in biomass [mgP/mgCOD]	0.02200	0.02200
Fraction to endogenous residue [-]	0.08000	0.08000
COD:VSS ratio [mgCOD/mgVSS]	1.42000	1.42000
Yield (anoxic) [-]	0.54000	0.54000
Yield propionic (aerobic) [-]	0.64000	0.64000
Yield propionic (anoxic) [-]	0.46000	0.46000
Yield acetic (aerobic) [-]	0.60000	0.60000
Yield acetic (anoxic) [-]	0.43000	0.43000
Yield methanol (aerobic) [-]	0.50000	0.50000
Adsorp. max. [-]	1.00000	1.00000

Methylotrophs

Name	Default	Value
Yield (anoxic) [-]	0.40000	0.40000
N in biomass [mgN/mgCOD]	0.07000	0.07000
P in biomass [mgP/mgCOD]	0.02200	0.02200
Fraction to endogenous residue [-]	0.08000	0.08000
COD:VSS ratio [mgCOD/mgVSS]	1.42000	1.42000

PAOs

Name	Default	Value
Yield (aerobic) [-]	0.63900	0.63900
Yield (anoxic) [-]	0.52000	0.52000
Aerobic P/PHA uptake [mgP/mgCOD]	0.95000	0.95000
Anoxic P/PHA uptake [mgP/mgCOD]	0.35000	0.35000
Yield of PHA on sequestration [-]	0.88900	0.88900
N in biomass [mgN/mgCOD]	0.07000	0.07000
N in sol. inert [mgN/mgCOD]	0.07000	0.07000
P in biomass [mgP/mgCOD]	0.02200	0.02200
Fraction to endogenous part. [-]	0.25000	0.25000
Inert fraction of endogenous sol. [-]	0.20000	0.20000
P/Ac release ratio [mgP/mgCOD]	0.49000	0.49000
COD:VSS ratio [mgCOD/mgVSS]	1.42000	1.42000
Yield of low PP [-]	0.94000	0.94000

Acetogens

Name	Default	Value
Yield [-]	0.10000	0.10000
H2 yield [-]	0.40000	0.40000
CO2 yield [-]	1.00000	1.00000
N in biomass [mgN/mgCOD]	0.07000	0.07000
P in biomass [mgP/mgCOD]	0.02200	0.02200
Fraction to endogenous residue [-]	0.08000	0.08000
COD:VSS ratio [mgCOD/mgVSS]	1.42000	1.42000

Methanogens

Name	Default	Value
Acetoclastic yield [-]	0.10000	0.10000
Methanol acetoclastic yield [-]	0.10000	0.10000
H2-utilizing yield [-]	0.10000	0.10000
Methanol H2-utilizing yield [-]	0.10000	0.10000
N in acetoclastic biomass [mgN/mgCOD]	0.07000	0.07000
N in H2-utilizing biomass [mgN/mgCOD]	0.07000	0.07000
P in acetoclastic biomass [mgP/mgCOD]	0.02200	0.02200
P in H2-utilizing biomass [mgP/mgCOD]	0.02200	0.02200
Acetoclastic fraction to endog. residue [-]	0.08000	0.08000
H2-utilizing fraction to endog. residue [-]	0.08000	0.08000
Acetoclastic COD:VSS ratio [mgCOD/mgVSS]	1.42000	1.42000
H2-utilizing COD:VSS ratio [mgCOD/mgVSS]	1.42000	1.42000

General

Name	Default	Value
Ash content of biomass (synthesis ISS) [%]	8.00000	8.00000
Molecular weight of other anions [mg/mmol]	35.50000	35.50000
Molecular weight of other cations [mg/mmol]	39.10000	39.10000
Mg to P mole ratio in polyphosphate [mmolMg/mmolP]	0.30000	0.30000
Cation to P mole ratio in polyphosphate [meq/mmolP]	0.30000	0.30000
Ca to P mole ratio in polyphosphate [mmolCa/mmolP]	0.05000	0.05000
Cation to P mole ratio in organic phosphate [meq/mmolP]	0.01000	0.01000
Bubble rise velocity (anaerobic digester) [cm/s]	23.90000	23.90000
Bubble Sauter mean diameter (anaerobic digester) [cm]	0.35000	0.35000
Anaerobic digester gas hold-up factor []	1.00000	1.00000
Tank head loss per metre of length (from flow) [m/m]	0.00250	0.00250

Mass transfer

Name	Default	Value	
Kl for H2 [m/d]	17.00000	17.00000	1.0240
Kl for CO2 [m/d]	10.00000	10.00000	1.0240
Kl for NH3 [m/d]	1.00000	1.00000	1.0240
Kl for CH4 [m/d]	8.00000	8.00000	1.0240
Kl for N2 [m/d]	15.00000	15.00000	1.0240
Kl for O2 [m/d]	13.00000	13.00000	1.0240

Physico-chemical rates

Name	Default	Value	
Struvite precipitation rate [1/d]	3.0000E+10	3.0000E+10	1.0240
Struvite redissolution rate [1/d]	3.0000E+11	3.0000E+11	1.0240
Struvite half sat. [mgTSS/L]	1.00000	1.00000	1.0000
HDP precipitation rate [L/(molP d)]	1.0000E+8	1.0000E+8	1.0000

HDP redissolution rate [L/(mol P d)]	1.0000E+8	1.0000E+8	1.0000
HAP precipitation rate [molHDP/(L d)]	5.0000E-4	5.0000E-4	1.0000

Physico-chemical constants

Name	Default	Value
Struvite solubility constant [mol/L]	6.9180E-14	6.9180E-14
HDP solubility product [mol/L]	2.7500E-22	2.7500E-22
HDP half sat. [mgTSS/L]	1.00000	1.00000
Equilibrium soluble PO4 with Al dosing at pH 7 [mgP/L]	0.01000	0.01000
Al to P ratio [molAl/molP]	0.80000	0.80000
Al(OH)3 solubility product [mol/L]	1.2590E+9	1.2590E+9
AlHPO4+ dissociation constant [mol/L]	7.9430E-13	7.9430E-13
Equilibrium soluble PO4 with Fe dosing at pH 7 [mgP/L]	0.01000	0.01000
Fe to P ratio [molFe/molP]	1.60000	1.60000
Fe(OH)3 solubility product [mol/L]	0.05000	0.05000
FeH2PO4++ dissociation constant [mol/L]	5.0120E-22	5.0120E-22

Aeration

Name	Default	Value
Alpha (surf) OR Alpha F (diff) [-]	0.50000	0.50000
Beta [-]	0.95000	0.95000
Surface pressure [kPa]	101.32500	101.32500
Fractional effective saturation depth (Fed) [-]	0.32500	0.32500
Supply gas CO2 content [vol. %]	0.03500	0.03500
Supply gas O2 [vol. %]	20.95000	20.95000
Off-gas CO2 [vol. %]	2.00000	2.00000
Off-gas O2 [vol. %]	18.80000	18.80000
Off-gas H2 [vol. %]	0	0
Off-gas NH3 [vol. %]	0	0
Off-gas CH4 [vol. %]	0	0
Surface turbulence factor [-]	2.00000	2.00000
Set point controller gain []	1.00000	1.00000

Modified Vesilind

Name	Default	Value
Maximum Vesilind settling velocity (Vo) [m/d]	170.0000	170.0000
Vesilind hindered zone settling parameter (K) [L/g]	0.3700	0.3700
Clarification switching function [mg/L]	100.0000	100.0000
Specified TSS conc.for height calc. [mg/L]	2500.0000	2500.0000
Maximum compactability constant [mg/L]	15000.0000	15000.0000

Double exponential

Name	Default	Value
Maximum Vesilind settling velocity (Vo) [m/d]	410.0000	410.0000
Maximum (practical) settling velocity (Vo') [m/d]	270.0000	270.0000
Hindered zone settling parameter (Kh) [L/g]	0.4000	0.4000
Flocculent zone settling parameter (Kf) [L/g]	2.5000	2.5000
Maximum non-settleable TSS [mg/L]	20.0000	20.0000
Non-settleable fraction [-]	0.0010	0.0010
Specified TSS conc. for height calc. [mg/L]	2500.0000	2500.0000

Biofilm general

Name	Default	Value	
Attachment rate [g / (m2 d)]	80.00000	80.00000	1.0000
Attachment TSS half sat. [mg/L]	100.00000	100.00000	1.0000

Detachment rate [g/(m3 d)]	8.0000E+4	8.0000E+4	1.0000
Solids movement factor []	10.00000	10.00000	1.0000
Diffusion neta []	0.80000	0.80000	1.0000
Thin film limit [mm]	0.50000	0.50000	1.0000
Thick film limit [mm]	3.00000	3.00000	1.0000
Assumed Film thickness for tank volume correction (temp independant) [mm]	0.75000	0.75000	1.0000
Film surface area to media area ratio - Max.[ ]	1.00000	1.00000	1.0000
Minimum biofilm conc. for streamer formation [gTSS/m2]	4.00000	4.00000	1.0000

Maximum biofilm concentrations [mg/L]

Name	Default	Value	
Non-polyP heterotrophs	5.0000E+4	5.0000E+4	1.0000
Anoxic methanol utilizers	5.0000E+4	5.0000E+4	1.0000
Ammonia oxidizing biomass	1.0000E+5	1.0000E+5	1.0000
Nitrite oxidizing biomass	1.0000E+5	1.0000E+5	1.0000
Anaerobic ammonia oxidizers	5.0000E+4	5.0000E+4	1.0000
PolyP heterotrophs	5.0000E+4	5.0000E+4	1.0000
Propionic acetogens	5.0000E+4	5.0000E+4	1.0000
Acetoclastic methanogens	5.0000E+4	5.0000E+4	1.0000
Hydrogenotrophic methanogens	5.0000E+4	5.0000E+4	1.0000
Endogenous products	3.0000E+4	3.0000E+4	1.0000
Slowly bio. COD (part.)	5000.00000	5000.00000	1.0000
Slowly bio. COD (colloid.)	0	0	1.0000
Part. inert. COD	5000.00000	5000.00000	1.0000
Part. bio. org. N	0	0	1.0000
Part. bio. org. P	0	0	1.0000
Part. inert N	0	0	1.0000
Part. inert P	0	0	1.0000
Stored PHA	5000.00000	5000.00000	1.0000
Releasable stored polyP	1.1500E+6	1.1500E+6	1.0000
Fixed stored polyP	1.1500E+6	1.1500E+6	1.0000
PolyP bound cations	1.1500E+6	1.1500E+6	1.0000
Readily bio. COD (complex)	0	0	1.0000
Acetate	0	0	1.0000
Propionate	0	0	1.0000
Methanol	0	0	1.0000
Dissolved H2	0	0	1.0000
Dissolved methane	0	0	1.0000
Ammonia N	0	0	1.0000
Sol. bio. org. N	0	0	1.0000
Nitrite N	0	0	1.0000
Nitrate N	0	0	1.0000
Dissolved nitrogen gas	0	0	1.0000
PO4-P (Sol. & Me Complexed)	1.0000E+10	1.0000E+10	1.0000
Sol. inert COD	0	0	1.0000
Sol. inert TKN	0	0	1.0000
Inorganic S.S.	1.3000E+6	1.3000E+6	1.0000
Struvite	8.5000E+5	8.5000E+5	1.0000
Hydroxy-dicalcium-phosphate	1.1500E+6	1.1500E+6	1.0000
Hydroxy-apatite	1.6000E+6	1.6000E+6	1.0000
Magnesium	0	0	1.0000
Calcium	0	0	1.0000
Metal	1.0000E+10	1.0000E+10	1.0000
Other Cations (strong bases)	0	0	1.0000
Other Anions (strong acids)	0	0	1.0000
Total CO2	0	0	1.0000
User defined 1	0	0	1.0000
User defined 2	0	0	1.0000
User defined 3	5.0000E+4	5.0000E+4	1.0000
User defined 4	5.0000E+4	5.0000E+4	1.0000
Dissolved oxygen	0	0	1.0000

Effective diffusivities [m2/s]

Name	Default	Value	
Non-polyP heterotrophs	5.0000E-14	5.0000E-14	1.0290
Anoxic methanol utilizers	5.0000E-14	5.0000E-14	1.0290
Ammonia oxidizing biomass	5.0000E-14	5.0000E-14	1.0290
Nitrite oxidizing biomass	5.0000E-14	5.0000E-14	1.0290
Anaerobic ammonia oxidizers	5.0000E-14	5.0000E-14	1.0290
PolyP heterotrophs	5.0000E-14	5.0000E-14	1.0290
Propionic acetogens	5.0000E-14	5.0000E-14	1.0290
Acetoclastic methanogens	5.0000E-14	5.0000E-14	1.0290
Hydrogenotrophic methanogens	5.0000E-14	5.0000E-14	1.0290
Endogenous products	5.0000E-14	5.0000E-14	1.0290
Slowly bio. COD (part.)	5.0000E-14	5.0000E-14	1.0290
Slowly bio. COD (colloid.)	6.9000E-11	6.9000E-11	1.0290
Part. inert. COD	5.0000E-14	5.0000E-14	1.0290
Part. bio. org. N	5.0000E-14	5.0000E-14	1.0290
Part. bio. org. P	5.0000E-14	5.0000E-14	1.0290
Part. inert N	5.0000E-14	5.0000E-14	1.0290
Part. inert P	5.0000E-14	5.0000E-14	1.0290
Stored PHA	5.0000E-14	5.0000E-14	1.0290
Releasable stored polyP	5.0000E-14	5.0000E-14	1.0290
Fixed stored polyP	5.0000E-14	5.0000E-14	1.0290
PolyP bound cations	5.0000E-14	5.0000E-14	1.0290
Readily bio. COD (complex)	6.9000E-10	6.9000E-10	1.0290
Acetate	1.2400E-9	1.2400E-9	1.0290
Propionate	8.3000E-10	8.3000E-10	1.0290
Methanol	1.6000E-9	1.6000E-9	1.0290
Dissolved H2	5.8500E-9	5.8500E-9	1.0290
Dissolved methane	1.9625E-9	1.9625E-9	1.0290
Ammonia N	2.0000E-9	2.0000E-9	1.0290
Sol. bio. org. N	1.3700E-9	1.3700E-9	1.0290
Nitrite N	2.9800E-9	2.9800E-9	1.0290
Nitrate N	2.9800E-9	2.9800E-9	1.0290
Dissolved nitrogen gas	1.9000E-9	1.9000E-9	1.0290
PO4-P (Sol. & Me Complexed)	2.0000E-9	2.0000E-9	1.0290
Sol. inert COD	6.9000E-10	6.9000E-10	1.0290
Sol. inert TKN	6.8500E-10	6.8500E-10	1.0290
Inorganic S.S.	5.0000E-14	5.0000E-14	1.0290
Struvite	5.0000E-14	5.0000E-14	1.0290
Hydroxy-dicalcium-phosphate	5.0000E-14	5.0000E-14	1.0290
Hydroxy-apatite	5.0000E-14	5.0000E-14	1.0290
Magnesium	7.2000E-10	7.2000E-10	1.0290
Calcium	7.2000E-10	7.2000E-10	1.0290
Metal	4.8000E-10	4.8000E-10	1.0290
Other Cations (strong bases)	1.4400E-9	1.4400E-9	1.0290
Other Anions (strong acids)	1.4400E-9	1.4400E-9	1.0290
Total CO2	1.9600E-9	1.9600E-9	1.0290
User defined 1	6.9000E-10	6.9000E-10	1.0290
User defined 2	6.9000E-10	6.9000E-10	1.0290
User defined 3	5.0000E-14	5.0000E-14	1.0290
User defined 4	5.0000E-14	5.0000E-14	1.0290
Dissolved oxygen	2.5000E-9	2.5000E-9	1.0290

EPS Strength coefficients [ ]

Name	Default	Value	
Non-polyP heterotrophs	1.00000	1.00000	1.0000
Anoxic methanol utilizers	1.00000	1.00000	1.0000
Ammonia oxidizing biomass	1.00000	1.00000	1.0000
Nitrite oxidizing biomass	1.00000	1.00000	1.0000
Anaerobic ammonia oxidizers	1.00000	1.00000	1.0000
PolyP heterotrophs	1.00000	1.00000	1.0000
Propionic acetogens	1.00000	1.00000	1.0000
Acetoclastic methanogens	1.00000	1.00000	1.0000
Hydrogenotrophic methanogens	1.00000	1.00000	1.0000
Endogenous products	1.00000	1.00000	1.0000
Slowly bio. COD (part.)	1.00000	1.00000	1.0000

Slowly bio. COD (colloid.)	0	0	1.0000
Part. inert. COD	1.00000	1.00000	1.0000
Part. bio. org. N	1.00000	1.00000	1.0000
Part. bio. org. P	1.00000	1.00000	1.0000
Part. inert N	1.00000	1.00000	1.0000
Part. inert P	1.00000	1.00000	1.0000
Stored PHA	1.00000	1.00000	1.0000
Releasable stored polyP	1.00000	1.00000	1.0000
Fixed stored polyP	1.00000	1.00000	1.0000
PolyP bound cations	1.00000	1.00000	1.0000
Readily bio. COD (complex)	0	0	1.0000
Acetate	0	0	1.0000
Propionate	0	0	1.0000
Methanol	0	0	1.0000
Dissolved H2	0	0	1.0000
Dissolved methane	0	0	1.0000
Ammonia N	0	0	1.0000
Sol. bio. org. N	0	0	1.0000
Nitrite N	0	0	1.0000
Nitrate N	0	0	1.0000
Dissolved nitrogen gas	0	0	1.0000
PO4-P (Sol. & Me Complexed)	1.00000	1.00000	1.0000
Sol. inert COD	0	0	1.0000
Sol. inert TKN	0	0	1.0000
Inorganic S.S.	0.33000	0.33000	1.0000
Struvite	1.00000	1.00000	1.0000
Hydroxy-dicalcium-phosphate	1.00000	1.00000	1.0000
Hydroxy-apatite	1.00000	1.00000	1.0000
Magnesium	0	0	1.0000
Calcium	0	0	1.0000
Metal	1.00000	1.00000	1.0000
Other Cations (strong bases)	0	0	1.0000
Other Anions (strong acids)	0	0	1.0000
Total CO2	0	0	1.0000
User defined 1	0	0	1.0000
User defined 2	0	0	1.0000
User defined 3	1.00000	1.00000	1.0000
User defined 4	1.00000	1.00000	1.0000
Dissolved oxygen	0	0	1.0000

Appendix D – Anaerobic Pond Outputs

Table 8. Anaerobic pond output data from the BioWin software

Elements	Volatile suspended solids [mgVSS/L]	Total suspended solids [mgTSS/L]	Volatile fatty acids [mg/L]	Total COD [mg/L]	Ammonia N [mgN/L]	pH []	Gas flow rate (dry) [m3/d]	Methane content [%]	VSS destruction [%]
Anaerobic Digester1	2335.58	2843.15	3.31	3957.94	86.51	7.00	594.76	3.04	0.00
Anaerobic Digester2	1614.73	2108.82	675.23	3495.09	106.95	7.00	144.50	72.86	30.86
Anaerobic Digester3	1216.25	1706.52	617.45	2807.65	119.86	7.00	239.12	75.61	24.68
Anaerobic Digester4	996.67	1486.14	193.05	2033.62	127.23	7.00	280.70	73.19	18.05
Anaerobic Digester5	849.26	1337.15	54.07	1662.09	134.17	7.00	138.39	72.07	14.79

Appendix E – Effluent Properties

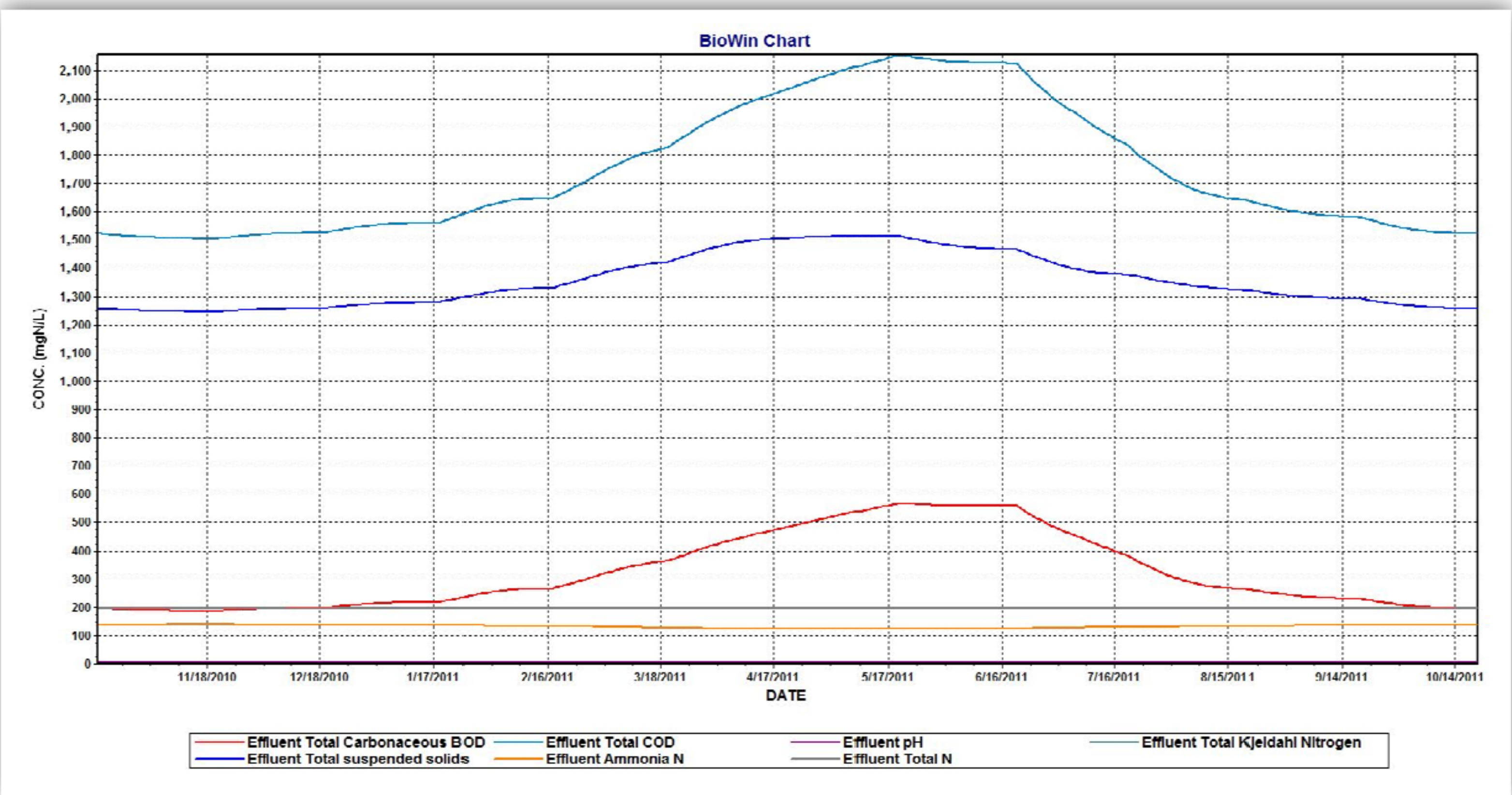


Figure 13. Effluent properties from the system over 1 year