EMISSIONS AND ECONOMICS OF BIOGAS AND POWER

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ABSTRACT

An emissions balance and economic screening methodology for applying High Rate Anaerobic Lagoon technology (coupled with electricity generation) to waste water treatment facilities.

It delivers a simple analysis that enables companies to focus on managing the total greenhouse gas emissions of an anaerobic lagoon to deliver an output that can be net positive for the environment.

Also includes a simple payback period methodology for converting from an existing facility to Anaerobic lagoon (coupled with electricity generation).

KEY WORDS

HRAL, High Rate Anaerobic Lagoon, Biogas, Electricity Generation

1.0 INTRODUCTION

Over the past five years there have been significant changes key areas of:

- Application of HRAL technology to waster water treatment facilities;
- Deregulation of the Australian electricity market place
- Global focus on managing total "footprint" Greenhouse Gas emissions

This paper has been developed by Diamond Energy to incorporate the most recent developments by Diamond Energy in applying current low BTU gas electricity generation technology with existing HRAL waste water treatment facilities at Goulburn Valley Water's Tatura, Shepparton and Mooroopna sites.

The paper outlines the economics for considering the application of HRAL technology and electricity generation at new and existing sites.

The aim is to deliver a high level screening tool to enable companies to look at the full impact of utilising HRAL (and other anaerobic) technology as a viable waste water treatment methodology in the current economic and emission management climate.

This paper should be read in conjunction with an Excel based program (that can be obtain free of charge from Diamond Energy) to do an overview economic analysis of potential waste water treatment sites. The Excel based program also compares HRAL direct and indirect emission's with that from other standard type waste water treatment designs. The Excel based program is an updated and modified version of a previous model that had been developed based on work completed under a joint partnership between the Victorian Environment Protection Authority, the Australian Centre for Cleaner Production, and Goulburn Valley Water in 2001.

2.0 DISCUSSION

2.1 Economic & Emissions Overview

The economics of utilising HRAL (and other anaerobic) technology coupled with electricity generation can be simplified as follows:

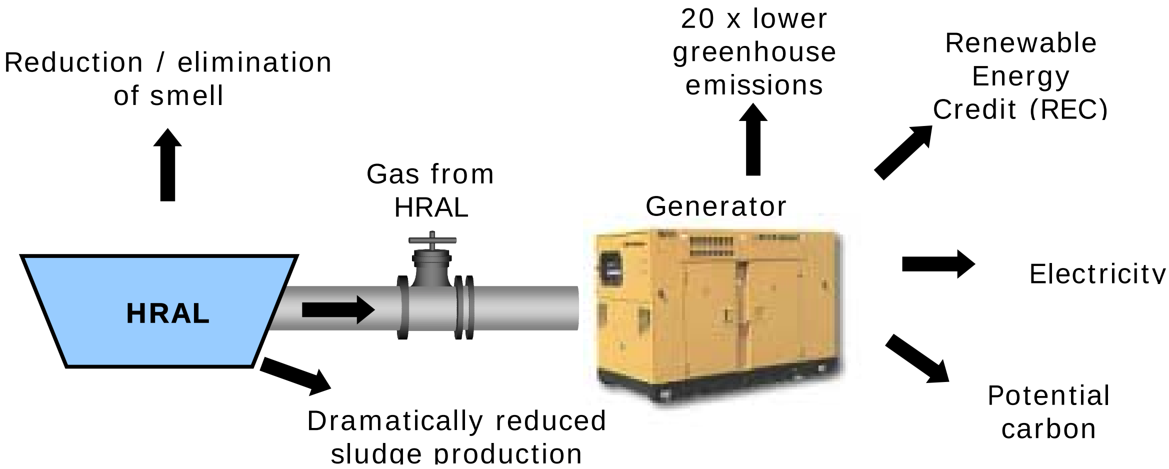


Figure 1: *Output Schematic*

Additionally the economic impacts of reduced indirect emissions from electricity consumption and emissions from chemical dosing should be included.

For simplicity the economics have been calculated using a value for the gas supplied to the generator, while the emission balance looks at the overall balance of the combined project.

In general the decision process can be broken down into following three key areas:

Economic Return for converting from an existing *operation*:

- Reduced operating costs (Reduced Sludge, Change in Chemical Dosage, Reduced Electricity Consumed)
- Increased Revenue (Value of Gas produced)
- Capital Cost

Emission Balance:

- Operating emissions (Anaerobic Emissions, Aerobic Emissions, Aerobic Sludge breakdown, Chemical Emissions, and Indirect Emissions such as lower electricity consumption)
- External Emissions Offset (Electricity produced that offset's coal fired generation)

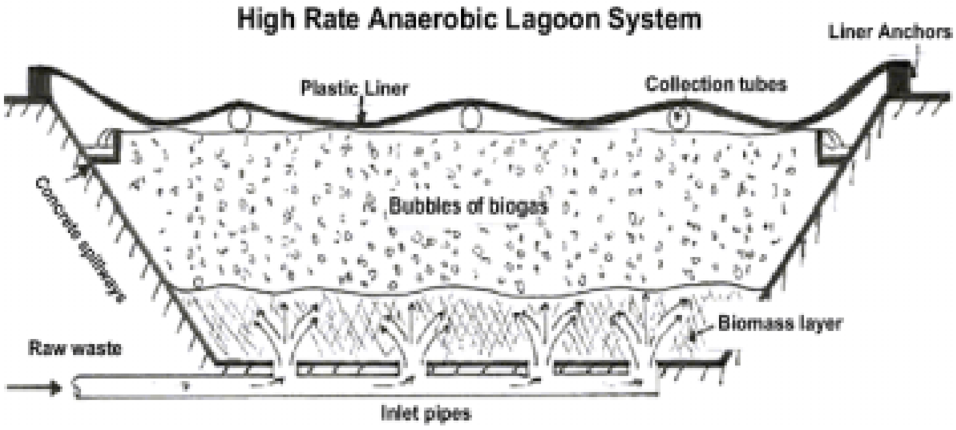
Extra Community Benefits:

- Reduced Smells/Odours
- Electricity produced supports local grid and local community
- Reduced sludge lowers waste handling and long term storage (especially for sludge that has heavy metal contamination)

2.2 HRAL Overview

The HRAL technology relies on the creation of a covered lagoon coupled to gas collection system.

- domestic and industrial influent COD levels measured in mg/Litre
- domestic and industrial influent flow rates measured in ML/day



<u>Figure 2:</u> *HRAL Schematic*

Key inputs are:

It is important to note that as the COD level decreases the size of the HRAL increases to maintain a meaningful residence time. This results in a capital cost increase and consequently the capital cost can increase to a point where the economic return decreases to below acceptable level.

2.3 Methodology of Economic Analysis

A simple payback period is calculated for converting from an existing Aerobic site to HRAL where:

Payback period = Capital Cost Economic Return / (change in Operating Costs + Increased Revenue)

2.4 Methodology of Emissions Analysis

Direct Emissions

The emissions from the HRAL are calculated using the Anaerobic emission factors as follows:

For a carbohydrate waste of composition $C_6H_{12}0_6$, the following anaerobic degradation reaction applies:

$$C_6H_{12}0_6 \rightarrow 3C0_2 + 3CH4 \qquad (1)$$

So it is expected that under anaerobic conditions, 3 mole of methane will be produced per mole of carbohydrate consumed; or 1 kg of carbohydrate yields (3x16/180) kg methane.

In the usual carbohydrate metabolizing process, the methane has an oxygen requirement for complete conversion to carbon dioxide and water, in accordance with the following reaction:

$3CH_4 + 60_2 \rightarrow 3C0_2 + 6H_20$ (2)

Therefore, the chemical oxygen requirement per kg of glucose equivalent converted is (6x32/180) kg chemical oxygen demand (COD).

Combining reactions (1) and (2), the potential amount of methane produced per kg of COD in the influent is:

kg CH_4 / kg COD = (48/180) / (192/180) = 0.25 kg CH_4 / kg COD removed

In accordance with the stoichiometry of equation (1), the number of moles of carbon dioxide produced will be the same as the number of moles of methane produced. However, in practice, the carbon dioxide will partially dissolve in the wastewater. The amount of carbon dioxide dissolved depends on the alkalinity of the wastewater and the vapour pressure of the system.

The emission factor for carbon dioxide in the anaerobic process is based on the emission factor for methane, incorporating the $C0_2$ to CH_4 ratio mentioned above.

The produced biogas will also be saturated with water vapour, and may contain other gases such as oxygen, nitrogen, ammonia, hydrogen sulphide and volatile organic gases. The volumes of these gases have not been explicitly calculated, but rather a total allowance has been made based on measured volumes from other similar systems.

For comparison purposes, the emissions from an Aerobic process assumes that by combining equations (1) and (2) and using and expected solubility of CO2 in water of 75% the number of moles of C02 released from the water in the aerobic process will be;

kg C02/kg COD = ((1- 75%) x (6 x 44)/180)/(192/180) = 0.344 kg C02/kg COD removed

Direct emissions are calculated on the basis of a generic treatment plant design, assuming a typical distribution of the COD removal between the various components of each treatment system.

Indirect Emissions

Each process requires chemical usage, a list of chemicals typically used for that process is used to estimate chemical dosage. Chemical usage is dependent on influent characteristics; using some expected rates an indicative chemical usage rate can be calculated.

The indirect emissions of carbon dioxide associated with chemical usage are estimated using emission factors for a range of commonly used chemicals.

Indirect emissions of carbon dioxide associated with the use of electricity are estimated as the sum of two contributors, electricity usage dependent on the rate of COD removal, and electricity usage dependent on the rate of wastewater/sludge pumping.

The indirect carbon dioxide emissions arising from the use of this electricity is estimated by applying a carbon dioxide emission factor to the anticipated usage. This emission factor has been obtained from the Sustainable Energy Authority of Victoria, and is representative of Victorian state average for electricity emissions.

2.5 Sludge Reduction

The HRAL's effectively convert COD into methane and this dramatically reduces the volume of sludge produced as compared to an Aerobic process, for the modelling the following has been used:

Standard Aerobic process produces 0.5 kg sludge / Kg COD
Standard Anaerobic process produces 0.05 kg sludge /Kg COD

The above are dependant on many factors, including residence time, temperature of reaction and bacteria utilised within the reactor.

2.6 Generation Potential – Gas Value

The methodology for the estimation of the generation potential of biogas produced by each treatment process builds on the previous methodology for emission factors. The amount of methane produced is calculated using the methane volume calculated in 4.5.1.

Assuming the methane capture is reduced to 98% due to losses through seals, flanges and solubilisation in the wastewater, the heating value is calculated by multiplying the mass of methane captured by its calorific value. This value represents a theoretical maximum heating value of the biogas. In practice, the biogas will not be 100% methane, even after scrubbing the gas and minimising carbon dioxide formation. Any inert gases present in the biogas will lower its heating value and value.

Potential power generation is calculated by multiplying the available methane chemical energy by combustion efficiency. The available energy for power conversion is reduced further due to inefficiencies in converting the methane chemical energy into mechanical energy, and then mechanical energy into electrical energy. These inefficiencies are accounted for in the generation efficiency factor.

For the modelling below the volume of methane produced is adjusted by efficiencies of the generator and gas system. The gas value is estimated by back calculating the return on the capital cost of the generator adjusted by the market risk factors.

2.7 Key Equations

Economic Return
Operating costs = Reduced Sludge Handling Costs – Change in Chemical Dosage + Reduced Electricity Consumed

Where:
Reduced Sludge Handling Costs = Change in Sludge volume x Sludge handling costs
Increased Revenue = Value of Gas x Generator Efficiencies x Volume of methane
Reduced Electricity Consumed = change in electricity consumed x cost of electricity
Capital Cost = volume of COD/day x residence time / depth of HRAL x Estimated cost per hectare

Emission Balance
Emission Balance = Anaerobic Emissions + Aerobic Emissions + Aerobic Sludge Breakdown Emissions + Chemical Emissions + Indirect Emissions + External Emissions

Offset
Where:
Anaerobic and Aerobic Emissions = see section 4.5.1
Aerobic Sludge Breakdown = Sludge volume x Aerobic emissions see section 4.5.1
Chemical Emissions = Chemical dosage volumes x Chemical emission factors per chemical
Indirect Emissions = change in electricity consumed x state electricity emission factor
External Emissions Offset = electricity exported x state electricity emission factor

2.8 Assumptions and Limitations

This is a simplistic modelling process, it should be used as an indicative calculation methodology to look at the value (both economic and emission balanced) of utilising HRAL technology

- All calculations are based on a standard design of each treatment.
- All emission factors have been calculated on the assumption that the waste consisted primarily of carbohydrate based substances.
- The proportion of anaerobic COD removal in treatment systems with both aerobic and anaerobic COD removal was chosen to reflect a typical design of each system.
- The generation potential is calculated assuming of 98% methane capture, 99% combustion efficiency, and 38% generation efficiency.
- Site Specific factors such as ambient temperature, electricity connection costs etc. have not been included.

2.9 Case Study

Assuming the following input data for a waste water treatment site:
COD level is 2000 mg/L
Influent feed at 6000 ML/annum

Emission Balance

Direct Emissions		
Aerobic	1238	CO2 tonne/yr
Anaerobic	1444	CO2 tonne/yr
	2682	CO2 tonne/yr
Methane produced	2,100	CH4 tonne/yr
Total Direct Emissions	8,457	CO2 tonne/yr
Note: Effective CO2 tonne year equivalent (after combustion of CH4)		
Indirect Emissions		
Chemical Usage	2307	CO2 tonne/yr
Electricity Consumed	278	CO2 tonne/yr
Sludge Aerobic Breakdown	764	CO2 tonne/yr
Total Emissions	**11,042**	**CO2 tonne/yr**
External Emissions Offset	-15,062	CO2 tonne/yr
Total Plant Emission Balance	**-4,020**	**CO2 tonne/yr**

i.e Plant is a net positive for Environment

Economic Return

Economic Return (for changeover from Aerobic Aerated Lagoon)		
Operating Costs		
Change Operation Staff	$ -	Assume no change
Reduced Sludge Handling	$ 94,500	
Value of Gas Produced	$ 264,600	
Reduced Electricity Consumption	$ 2,130,000	
Increased Chemical Dosage	$ 766,080	
Total Plant Operating Savings	**$ 1,723,020**	per Year
Capital Cost		
Approximate Lagoon Size	6.4	Hectares
Capital Cost of HRAL	**$ 15.5**	Million Dollars
Simple Payback Period	**9.01**	Years

Key Conversion Factors

100	% Design Treatment Efficiency	
0.344	Emission factor for aerobic process (kg CO2/kg COD removal)	
30	% COD removal that is aerobic	
0.25	Emission factor for anaerobic process (kgCH4/kg COD)	
0.25	Ratio of $n(CO_2)$: $n(CH_4)$	
2.75	CO2/CH4 molecular weight ratio	
Cost		
$/Tonne	Chemical Emission Factors (tCO2/t product produced)	
$ 200	0.84	Sodium Hydroxide
$ 800	0.723	Urea
$ 200	1.63	Alum
$ 1,400	1	Monoammonium Phosphate
Anaerobic Chemical Usage		
600	tonne/annum	Indicative additional hydroxide required
585.6	tonne/annum	Indicative available nitrogen required
780	tonne/annum	Indicative alum required for algae control
108	tonne/annum	Indicative available phosphorus required
0	HRAL Aeration Energy factor (kWh/kg BOD) or (kWh/kg COD)	
1.2	Aerated Lagoon Energy factor (kWh/kg BOD) or (kWh/kg COD)	
12	Pumping factor (kW per 100L/s @ 5m head)	
0.386	Emission factor (tonne CO2/GJ)	
0.5	Aerobic Sludge Kg Sludge/ Kg COD	

0.05	Anaerobic Sludge Kg Sludge/ Kg COD	
38%	Electrical Efficiency of Generator	
98%	Methane Capture	
99%	Combustion Efficiency	
50.40	CH4 Calorific Value MJ/Kg	
$ 25	Sludge Handling Cost $/Tonne	
$ 126	Gas Value $ /Tonne CH4	
$ 0.15	Delivered Electricity Price cents/kWh	
Aerobic Aerated Lagoon Chemical Dosage		
120.0	tonne/annum	Indicative available nitrogen required
24.0	tonne/annum	Indicative available phosphorus required
7	Residence Time (days)	
$ 1.00	Base Starting cost (Million $)	
$ 2.40	Flat Cost per Hectare (Million $)	
0.02	Cost deflator $ Million saved per Hectare^2	

3.0 CONCLUSIONS

The modelling shows that for HRAL's coupled with electricity generation:

- Total Emission balance can be net POSITIVE for the environment
- Payback Periods of 9 years can be obtained when converting from Aerated Aerobic Lagoons to HRAL's

Additionally:

- The application of HRAL's are dependent on the influent COD levels and rates
- Due to the site specific factor's additional research should be done to determine the emission balance and economics for a specific site.

4.0 ACKNOWLEDGEMENTS

This work has been based on the based on a study completed under a joint partnership between the Victorian Environment Protection Authority, the Australian Centre for Cleaner Production, and Goulburn Valley Water in 2001.

5.0 REFERENCES

The original greenhouse gas model developed by the Victorian Environment Protection Authority, the Australian Centre for Cleaner Production and Goulburn Valley Water can be found at:

www.epa.vic.gov.au/EPA/Publications.NSF/PubDocsLU/greenhouse_emission_model

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