Waste To Energy Plant for
Siam Quality Starch Ltd
Thailand

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CONTENTS

Appendix IV

Large scale system for biogas harvesting and mitigation of fugitive methane emissions

Large scale system for biogas harvesting and mitigation of fugitive methane emissions

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Abstract Sanguan Wongse Industries is Thailand's largest producer of tapioca starch. A highly concentrated, highly degradable effluent stream (equivalent to a COD load of 185 tonnes/day) was largely converted into biogas in an extensive open lagoon system leading to the emission of large volumes of methane to atmosphere. A baseline evaluation of the potential to harvest biogas for energy use indicated a Carbon Emission Reduction potential of about 370,000 Metric Tonnes Carbon Equivalent per annum. A Covered In-Ground Anaerobic Reactor (CIGAR) was constructed to harvest biogas. During Phase 1 of the project, a median volume of over 25,000 m^3/d of biogas was used for fuelling starch dryers in the factory. During Phase 2, 3.15 MW of electricity generation capacity was installed effectively doubling the gas utilisation rate. The CIGAR has a nominal design biogas production capacity of nearly 120,000 m^3/d, sufficient for the addition of further electricity generation potential and catering for future growth of the company. The biogas generation potential of the CIGAR is considered sufficient to make the company fully energy independent and in addition generate a surplus of electrical energy for delivery to the national grid.
Keywords Tapioca starch; cassava; Thailand; methane emissions; greenhouse gas; high-rate lagoon; waste to energy

Introduction

Sanguan Wongse Industries (SWI), Khorat, Thailand is Thailand's largest producer of tapioca starch producing 12% of the Thai national total of 1.8 to 2.0 million tonnes per annum. In 2002, SWI's processing plant discharged an estimated average flow of 6,600 m^3 of wastewater with an average COD content of 28,000 mg/L, equivalent to a total COD mass load of 185 tonnes per day.

Prior to the construction of a waste-to-energy plant the wastewater flowed through an extensive constructed lagoon system consisting of 78 anaerobic and facultative lagoons with a total length of more than 70 km. The organic constituent of the wastewater is effectively degraded to specifications meeting the Thai Pollution Control Department consent limits at an average 38 mg/l BOD_5 and 63 mg/l SS. As a result of all-year ambient temperatures of around 30-35 ^oC and high organic loading rates, a number of the lagoons which are first in line to receive the wastewater have become anaerobic and act as active anaerobic digestion systems, emitting large volumes of methane to the atmosphere. An initial evaluation was carried out to estimate fugitive methane emissions from the existing lagoon system. This data was used to establish a baseline scenario for the trading of greenhouse gas Carbon Emission Reduction (CER) credits under the Clean Development Mechanism (CDM) of the Kyoto Protocols.

A high rate Covered In-Ground Anaerobic Reactor (CIGAR) system was constructed to treat SWI's wastewater and convert the organic load into biogas. The main purposes of the project were to reduce the dependency of SWI on imported fuels and energy (oil and electricity) and to reduce the emissions of methane from the existing facultative lagoon system. The plant was commissioned in early 2003. This paper reports on data obtained on the SWI site prior to construction and performance results obtained since the commissioning of the plant.

Methods

Site evaluation

A Feasibility and Technical Evaluation was carried out in January 2001 (Cohen, 2001). This included wastewater sampling and analysis and a performance assessment of the existing lagoon system.

CDM Baseline establishment.

According to the CDM rules stipulated by United Nations Framework Convention on Climate Change UNFCCC and the Kyoto Protocol, a project must select a baseline methodology to assess carbon emissions prior to the commencement of the project. This baseline is incorporated into a Monitoring and Verification Plan (M&VP) which sets out to monitor performance and compliance of a project once it has gained approval for accreditation.

Routine COD analyses were carried out on weekly composites of daily collected grab samples of raw effluent and from various locations at the existing lagoon system during the period from May until July 2004 and prior to the construction of the CIGAR.

Pilot trials

A 4.5 m^3 pilot plant was used to test anaerobic treatment of SWI's wastewater under realistic conditions at the site prior to the construction of the CIGAR.

Process monitoring on full-scale plant

Flow of raw influent into the plant is measured by a Parshall Flume flow meter; gas flow is measured by an averaging Pitot Tube mass flow meter; methane content of the biogas is measured by infrared spectrometry.

Results and discussion

Feasibility and Technical Evaluation

Wastewater composition. Raw wastewater samples were analyzed with the following results (average of three samples collected on three consecutive days, all results expressed as g/m^3 except pH): pH: 6.1; CODt: 32,000; CODf: 10,319; BOD5: 7,583; SS 20,617; VSS: 19,433; TKN: 415 and ammonia-N: 50.0. The average temperature was 32.9 ^oC.

Methane emissions from anaerobic lagoons. Three lagoons of the existing lagoon system first in line to receive the wastewater (Lagoons 1-3) were largely filled with settled solids, but three lagoons following in the series were showing signs of active biogas production (Figure 1).

Figure 1 Flow channel on the surface of Lagoon 1 (left) and active gas production on Lagoon 4 (right).

CDM Baseline establishment

Fugitive methane emissions to atmosphere prior to the construction of the CIGAR were estimated from COD reductions which took place in Lagoons 4-6 (Table 1). Maximum methane emissions were assumed to be equal to 350 Nm^3 of methane per tonne of COD removed, less COD removed by surface oxidation. The total daily flow of wastewater into the lagoons was measured (Cohen, 2002) and estimated from factory production mass balances to be within the range between 260 and 270 m^3/h.

Table 1 COD removal in first three active anaerobic lagoons at an average flow of 260 m^3/h. Samples were collected at factory discharge (after removal of course solids by screening) and exit points of lagoons 4, 5 and 6 respectively.

	Factory	Lagoon 4	Lagoon 5	Lagoon 6
Average COD (kg/m^3) at exit point	28.0	4.38	2.81	0.82
Standard deviation	6.95	1.56	2.46	1.70
Total COD removed (tonnes/d)	-	147	9.80	12.4
Estimated loss by surface oxidation (tonnes/d)	-	1.03	0.23	0.17
Estimated net fugitive methane emission (Nm^3/d)	-	51,089	3,349	4,280

As a result, the first lagoons received an estimated daily load of 178 tonnes of COD. The baseline scenario was conservatively established on the basis of COD removed up to (and including) lagoon 4 only with further downstream COD degradation not being included. COD losses by surface oxidation was estimated at 245 kg per hectare per day and the combined surface area was estimated at 41,858 m^2 (Guest and Cohen, 2003).

Table 2 Projected Carbon Emission Reductions over a 7 year accreditation period (all figures expressed as Metric Tonnes Carbon Equivalent)

	Electricity emissions		Oil emissions		Lagoon emissions		Total annual emissions		
Term	Baseline	Project	Baseline	Project	Baseline	Project	Annual Baseline Emissions	Annual Project Emissions	Annual Emissions Reductions
Mar - Dec 2003	15,852	11,535	20,596	0	261,711	25,999	298,159	37,534	260,625
2004	22,282	7,002	26,616	0	338,337	33,724	387,235	40,727	346,508
2005	24,175	8,702	28,518	0	362,620	36,250	415,313	44,952	370,361
2006	24,101	8,676	28,518	0	362,620	36,250	415,239	44,926	370,313
2007	23,313	8,392	28,518	0	362,620	36,250	414,451	44,642	369,809
2008	22,892	8,240	28,518	0	362,620	36,250	414,030	44,490	369,539
2009	22,661	8,157	28,518	0	362,620	36,250	413,798	44,407	369,391
Jan - Feb 2010	3,832	1,379	4,753	0	60,437	6,042	69,021	7,421	61,600
Total	15,852	62,085	194,553	0	2,473,586	247,015	2,827,247	309,100	2,518,147

Factory energy use and CER projections

Rather than converting the existing lagoons for the extraction of biogas it was decided that a new, high rate anaerobic plant was to be constructed. The generated biogas would be used to feed the four factory starch dryers, with the surplus of gas to be used for the generation of electricity.

The project would lead to carbon emission reductions in three ways:

1. **Mitigation of fugitive methane emissions from existing lagoons.** The capture of methane for energy generation (combustion to CO_2) and the elimination of the emission of methane to atmosphere by the open lagoons is the most important factor in the reduction of carbon emissions (the Global Warming Potential of methane is 21, i.e., one tonne of methane has an effect equivalent to 21 tonnes of CO_2)
2. **Substitution of fuel oil use.** Methane used for heating purposes substitutes the estimated use of 6,000,000 litres of Heavy Fuel Oil used annually by SWI (at the time of project inception) for the drying of starch
3. **Electricity generation.** Substitution of carbon emissions from fossil fuel use to generate grid electricity. At the time of project inception SWI consumed 4.6 MW of electrical energy.

Table 2 shows an outline of projected carbon emission reductions over an accreditation term of seven years. This takes into account projected growth in production capacity (from 550 tonnes of starch per day in 2002 increasing to 700-800 tonnes per day near the end of 2004). The project appears to conform to international expectations in relation to the CDM and sustainable development objectives. These CER's, will be offered to Annex I (developed country) companies seeking carbon offsets under the Kyoto Protocols.

Pilot evaluation

The degradability of the waste and methane generation potential were evaluated on pilot scale on the site over a period of three months, using factory wastewater collected at the main discharge point. The result obtained at design load are summarised in Table 3.

Table 3 Results of pilot scale evaluation of methane generation potential

	Raw waste composition				Process performance results			
	CODt (g/m^3)	CODs (g/m^3)	SS (g/m^3)	VSS (g/m^3)	Methane (%)	Temperature (°C)	Gas per kg COD added (Nm^3/kg)	Methane per kg COD added (Nm^3/kg)
Average	27,975	9,621	16,113	15,743	60.6	33.8	0.58	0.35
Standard Deviation	7,305	2,688	5,581	5,582	1.1	0.9	0.15	0.09

The results presented in Table 3 show that the wastewater contained very high levels of suspended solids with very low ash content. The most surprising result was that on average 0.35 m^3 methane was recovered per kg COD fed to the plant. This is equal to the theoretical conversion of COD into methane. As part of the COD is converted into biomass this figure is unrealistically high. It was concluded that the very high methane recovery was the result of sampling errors. Fast settling of suspended solids were presumed to cause difficulty in obtaining representative samples leading to an under-estimation of the true COD concentration of the raw waste. On average, it was found that per m^3 of raw wastewater 15.7 m^3 of biogas was produced.

Planning a full scale waste to energy plant

A projection was made of the energy production potential by a full scale facility on the basis of wastewater analysis results, pilot evaluation results and data provided by SWI, indexed for the year 2002. Table 4 shows that if all available COD would be effectively used it could make SWI completely energy independent and in addition generate an electrical surplus. Construction was planned to proceed in three phases: Phase 1 - delivery of gas to four factory starch dryers; Phase 2 – the addition of 3.15 MW electrical power generating capacity, and Phase 3 – addition of further electricity generation capacity.

At the installation of the initial electrical power generating capacity during Phase 2 (and assuming 92% availability) this will substitute 62% of SWI's 4.66 MW electrical energy use. On a total of 683 GJ/d thermal energy use plus 402 GJ/d electricity use, Phases 1 and 2 combined would supply a total of 932 GJ/d thus making the company 86% energy independent. Phase 3 would take further production growth (and concomitant increase of wastewater discharge) into account to add further electrical generation capacity to match demand and even generate a surplus for delivery to the national grid.

All predictions in this paper are based on 2002 production levels. At an average methane content of approximately 61% and 330 processing days per annum the annual total gas production would amount to more than 33 million m^3. With starch production levels growing annually by at least 10% this will lead to further increases in energy production and energy utilization by SWI.

Table 4 Daily mass and energy balance based on SWI 2002 production levels

	Value	Unit
Wastewater flow	6,626	m^3/d
Average COD	28.0	Kg/m^3
COD mass load	185,640	Kg/d
Methane available at 95% COD removal efficiency	61,725	Nm^3/d
Total biogas thermal energy value at 35.9 MJ/Nm^3	2,216	GJ/d
Heavy Fuel Oil used	16,701	L/d
Heavy Fuel Oil thermal energy value at 40.9 MJ/l	683	GJ/d
Methane use to substitute HFO	19,027	Nm^3/d
Surplus methane for electricity generation	42,698	Nm^3/d
Surplus energy for electricity generation	1,532	GJ/d
Electricity generation potential at 39 % efficiency and 92% availability factor	6.37	MWe
Electrical units	152,775	kWh/d
Actual electrical use	111,801	kWh/d

Plant design and construction (CIGAR Performance results)

Phase 1 of the project (CIGAR construction and gas delivery to SWI's starch dryers) involved a total investment of US$ 1.4 million. Phase 2 involved the addition of 3.15 MW electrical power generating capacity (US$ 2.0 million). The planning of Phase 3 was not yet completed at the time of writing of this publication but would be expected to involve the addition of at least a further 2.10 MW of electrical power generation capacity.

The design of the plant was specifically targeted towards process reliability, capital and operating cost savings. Nominal and peak COD load are 200,000 and 235,000 kg/d with projected gas production at 118,000 and 137,000 m^3/d respectively.

Figure 2 Left photograph: The CIGAR in the foreground with SWI starch production facility in the background. The electrical power plant building is at the centre. Right photograph: gas engines and electricity generators.

Plant performance results

The plant was commissioned in April 2003. From May 2003 until February 2004 gas was delivered to SWI starch dryers only, with some surplus gas flared off. No measurements were taken of the volume of gas flared off as an accurate gas meter was not installed on the flare line until Phase 2. The electric power plant was commissioned during March of 2004 and has been in operation for about one month at the time of writing of this publication. Here we report the first performance data since commissioning. The results for Phases 1 and 2 are summarised in Table 5.

The results of the pilot trials has indicated that per m^3 of wastewater treated on average 15.7 m^3 biogas was recovered. Since the commissioning of Phase 2, median gas production per m^3 of

wastewater was 14.9 m^3/m^3 which is in good agreement. Differences are thought to be the result of measurement errors by the Parshall Flume flow meter in particular which was used to measure influent flow with a lower accuracy than the magnetic flow meter used at the pilot plant.

Assuming 15.7 m^3 biogas per m^3 of wastewater, the expected median total gas yield during Phase 1 would have been in the order of 49,300 m^3/day. Total median gas yield after the commissioning of Phase 2 was 62,500 m^3/d, with peak gas production reaching over 81,000m^3/d.

Excellent removal of COD, BOD_5 and TSS were reported. However during the period between 27/8/2003 and 25/11/2003 maximum sludge levels were reached in the CIGAR leading to sludge washout which led to a temporary deterioration of the effluent quality. Removal efficiency figures fully restored after excess sludge was removed from the CIGAR.

Table 5 Summary results of plant operation. All observations reported as median values ± standard deviation. [1]An accurate gas meter on the flare gas line was installed during the commissioning of Phase 2. [2]Weekly analyses over the period from 4/6/2003 until 27/1/2004. [3]Results reported from start-up of power generation on 18/4/2004 until 11/05/2004.

	Phase 1	**Phase 2[3]**
Median influent flow (m^3/d)	3,140 ± 746	4,207 ± 977
Biogas to starch dryers (m^3/d)	25,187 ± 7,372	30,850 ± 9,798
Biogas to electricity (m^3/d)	n/a	27,028 ± 9,963
Biogas to flare (m^3/d)	n/a[1]	10,535 ± 6,356
Median methane content (%)	60.9 ± 1.9	61.6 ± 1.0
COD reduction (%)[2]	96.2 ± 3.5	n/a
BOD reduction (%)[2]	99.3 ± 0.4	n/a
TSS reduction (%)[2]	93.3 ± 7.3	n/a
Volume of biogas produced per m^3 of wastewater	n/a[1]	14.9 ± 3.3

Future scope

Since the planning of the project, when starch production was at a level of approximately 550 tonnes per day starch production has grown to about 750 tonnes per day with a concomitant increase in energy demand (heating and electricity). At the time of writing of this publication total energy demand was estimated in the order of 8.6 million litres of Heavy Fuel Oil per annum and 6.3 MW of electrical power. Complete substitution by biogas would imply a daily consumption of about 114,000 m^3 of biogas at a methane content of 60%. At a design nominal gas production capacity of 120,000 m^3/d there is sufficient potential to further increase energy production to meet the current demand and the addition of a further 2-3 MW electricity generation capacity is under consideration.

Conclusions

1. The tapioca starch processing wastewater discharged at SWI is a highly concentrated, highly biodegradable resource with sufficient energy generating potential to make the factory fully energy independent
2. The construction of a full scale CIGAR has proven an effective and economic means to generate low cost energy and to mitigate fugitive emission of large volumes of methane to atmosphere

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