final report

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Integrated agroindustrial wastewater treatment and nutrient recovery

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1. Milestone

The project milestone was due in the period covered by this report:

- Anaerobic digestibility determined: 1-Jun-2012

2. Abstract

The high-rate aerobic process has been evaluated by varying the sludge retention time (SRT) between 2-4 days and hydraulic retention time (HRT) between 0.5-1 day in sequencing batch reactor (SBR). This process is most effective under operating conditions of 0.5 day HRT and 2-3 days SRT, with >80% of carbon and phosphorus removal and >50% nitrogen removal. The high phosphorus removal efficiency was achieved by biological phosphorus removal process, and the functional microorganisms responsible for this are being identified. Anaerobic degradability of waste activated sludge generated from the high rate process has been determined using batch tests and model analysis. Results showed the sludge can be successfully digested (>70% degradability) to release the carbon in the form of methane through either mesophilic (37°C) or thermophilic (>55°C) processes, with thermophilic process achieving higher space-loading rates, but not higher degradation extent. Assessment of dewaterability of the digested sludge showed that the free water content was generally <10%, indicating solar drying could be a suitable dewatering method in practice.

3. Project objectives

The outcome of this project will be the evaluation of a novel, innovative technology to maximise the COD and nutrient removal performance while minimising the energy demand for the treatment of meat processing wastewater. While this project will focus on the development and demonstration of the process at the laboratory scale, it will identify major design and performance parameters that will be essential for the evaluation of the possible suitability and economics of the process once implemented at full-scale.

Therefore, this project will have as a key output the design, operating and performance parameters for this innovative technology that could provide an economic alternative to current treatment options in situations where nutrient removal is important and/or space availability is limited and hence anaerobic lagoons plus SBRs are not an ideal option.

Further work would then be required to demonstrate the technology on site at a pilot scale, but this is not part of the current project scope at this stage.

4. Success in achieving milestone

<u>High-rate Aerobic Process Performance</u>

While approaching project milestone 3, the operating parameters for the high-rate aerobic process have been further optimised by varying the SRT of the SBR (under 0.5 day HRT conditions). After optimising SRT for the SBR, the HRT of the SBR was extended from 0.5 day to 1 day to further evaluate the effect of HRT on the aerobic process. Below are the different operating conditions in the SBR that have been tested in this project:

- Period 1 (55 days): 2 days SRT, 0.5 day HRT
- Period 2 (33 days): 3 days SRT, 0.5 day HRT
- Period 3 (21 days): 2 days SRT, 0.5 day HRT, which aimed to assess whether the SBR performance was reproducible
- Period 4 (28 days): 4 days SRT, 0.5 day HRT
- Period 5 (27 days): 2.5 days SRT, 0.5 day HRT
- Period 6: 2.5 days SRT, 1 day HRT, which is the current operating condition for evaluation of the HRT effects.

N and P removal are key performance indicators used in this project to evaluate the aerobic process for nutrient removal from the wastewater. The SBR has achieved approx. 56% total N removal during the operations of 2 days, 2.5 days and 3 days SRT, as shown in Table 1. However, extending the SRT further to 4 days has resulted in a decrease of total N removal to 47%, which was probably due to the large portion of COD oxidation (approx. 50% COD was oxidised), which released part of the organic N bound in the sludge. Total P removal in the SBR was approx. 50% during the initial 2 days SRT operation, and increased to 78% at 2.5 days SRT and further to 85% at 3 days and 4 days SRTs, with only 1 mg/L phosphate-P remaining in the effluent. This high P removal efficiency is most likely due to biological phosphorus (Bio-P) removal, which has developed after the initial 2 days SRT operation. This was clearly demonstrated in the cycle studies and supported by chemical analysis. In the second operating period with 2 days SRT, Bio-P activity could even be achieved under these conditions with over 90% PO_4-P removal. Achieving Bio-P removal in an SBR at such a short SRT is very promising and has not been shown before to be possible. Extending the HRT of the SBR from 0.5 day to 1 day (while maintaining the SRT at 2.5 days) did not have a significant impact on the nutrient removal efficiency.

Table 1. A summary of nutrient removal performance in the SBR under different operating conditions.

SRT/HRT	Total N removal (%)	NH_4^+-N removal (%)	Total P removal (%)	PO_4^{3-}-P removal (%)	MLSS (g/L)
2d / 0.5d	51.7	41.9	50.0	58.7	3.6
3d / 0.5d	58.6	42.0	84.7	95.8	4.1
2d /0.5d	59.3	42.3	76.8	90.7	3.0
4d / 0.5d	47.4	18.8	85.2	88.8	5.0
2.5d / 0.5d	61.5	39.8	84.3	91.3	3.2
2.5d / 1d	57.3	38.6	88.6	91.1	2.6

COD removal is another key process performance measure used in this project. As shown in Table 2, the SBR has achieved approx. 87% COD removal in all the operating periods. The removed COD has also been proved to be mainly (approx. 70-80%) used for biomass growth/accumulation (except for the operation of 4 days SRT), rather than oxidation. This is as what we expected and will drastically reduce aeration requirements (corresponding to lower electricity requirements) when considered in real applications. In turn it will maximise the COD being transferred into biomass, which can then be anaerobically digested to produce biogas (see below). The biological oxygen demand (BOD) of the effluent from the SBR was below 100 mg/L, which has met the requirement for irrigation, but would require some polishing if discharge to waterways was desired.

Given the results of nutrient removal and COD removal in the SBR reported above, the high-rate aerobic process is more effective under operating conditions of 0.5 day HRT and 2-3 days SRT, with >80% of carbon and phosphorous removal and >50% nitrogen removal.

Table 2. A summary of COD removal performance in the SBR under different operating conditions.

SRT/HRT	tCOD removal (%)	sCOD removal (%)	COD removed (gCOD/L/d)	COD oxidised (gCOD/L/d)	Fraction (%)	BOD (mg/L)
2d / 0.5d	86.6	80.6	2.87	0.75	26.3	-
3d / 0.5d	86.4	79.5	3.38	1.09	32.4	-
2d / 0.5d	86.2	77.6	3.04	0.62	20.5	90.3
4d / 0.5d	89.3	84.7	3.57	1.75	49.2	56.5
2.5d / 0.5d	88.1	85.9	3.74	1.06	28.3	15.7
2.5d / 1d	89.3	85.6	1.49	0.32	21.5	-

Anaerobic degradability of waste activated sludge

To determine the anaerobic degradability of the waste activated sludge generated in the high-rate aerobic SBR, three different anaerobic sludge treatment processes have been tested under batch conditions in this study, namely: (i) single-stage mesophilic (37°C) anaerobic digestion (AD), (ii) single-stage thermophilic (55°C) AD and (iii) temperature phased anaerobic digestion (TPAD) (2 days at 55°C, followed by 37°C). In these batch tests, methane production was monitored throughout the degradation period, as shown in Figure 1 (the cumulative methane productions from the batch tests for the 2 days SRT sludge). The methane production curve of each digestion test was fitted by a first order kinetic model, which was implemented in Aquasim 2.1d. Estimations of sludge degradability (extent of degradation, f_d) and apparent hydrolysis coefficient (rate of degradation, k_{hyd}) were based on the gas flow measurements. Results of degradability analysis for each sludge digestion test are summarised in Table 3, and the results of the mesophilic and thermophilic digestion are illustrated in Figure 2.

For the 2 days SRT sludge, statistically, the three anaerobic processes offered a similar degradability extent (approx. 84%) and hydrolysis rate (approx.0.29 d^{-1}). For the sludge with 3 days and 4 days SRT, the degradability extents were also similar in the three anaerobic processes, with approx. 73% f_d for the 3 days SRT sludge and approx. 63% f_d for the 4 days SRT sludge (see Table 3 and Figure 2). However, the hydrolysis rate (which is generally considered as the rate-limiting step in anaerobic digestion) was significantly improved under thermophilic AD compared to others (Figure 2), indicating single-stage thermophilic AD with a short HRT (e.g. 5-8 days) could achieve a high sludge degradability in full scale plants (corresponding to small volume of vessels and capital investments). Moreover, high degradability of the sludge with shorter SRTs in full scale plants translates to high methane production, as shown in Figure 1, approx. 370 L methane per kgVS produced from 2 days SRT sludge digestion. This high methane production can be used to produce heat and power for the whole treatment process, which will significantly reduce the energy demand and should achieve a total net energy generation from the overall process.

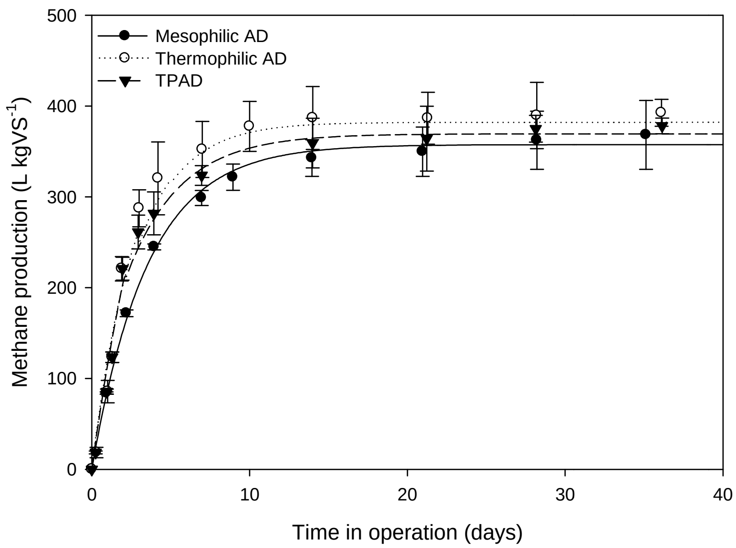

Figure 1. Cumulative methane production from mesophilic and thermophilic AD batch tests and TPAD batch tests with model fitted for 2 days SRT sludge (Error bars are 95% confidence intervals based on triplicate batch tests).

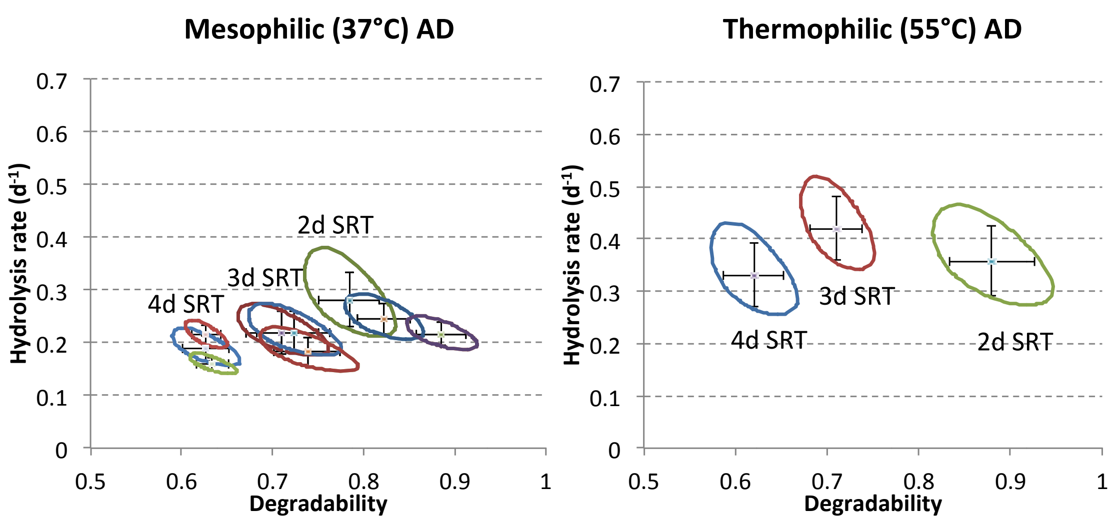

Figure 2. Degradability extent and rate of the high-rate aerobic waste sludge under mesophilic and thermophilic conditions. The degradability clearly increases with shorter sludge ages in the aerobic stage, while the hydrolysis rate remains similar for each digestion temperature, but is higher under thermophilic than under mesophilic conditions.

Table 3. Estimates of apparent hydrolysis coefficient (k_{hyd}) and degradability extent (f_d) in three anaerobic digestion processes for the activated sludge with 2 days, 3 days, 4 days SRT.

		2d SRT	3d SRT	4d SRT
Single-stage mesophilic AD	k_{hyd}	0.25 ± 0.029[a]	0.22 ± 0.043	0.19 ± 0.024
	f_d	0.82 ± 0.026	0.71 ± 0.042	0.63 ± 0.026
Single-stage thermophilic AD	k_{hyd}	0.36 ± 0.067	0.42 ± 0.061	0.33 ± 0.061
	f_d	0.88 ± 0.046	0.71 ± 0.028	0.62 ± 0.032
TPAD	k_{hyd1}[b]	0.24 ± 0.023	0.28 ± 0.036	0.21 ± 0.023
	k_{hyd2}[c]	0.29 ± 0.098	0.12 ± 0.048	0.13 ± 0.046
	f_d	0.86 ± 0.055	0.79 ± 0.042	0.65 ± 0.025

a: Error margins indicate uncorrelated linear estimates of errors by model fitting at a 95% confidence level.
b: Apparent hydrolysis coefficient in the first thermophilic stage in TPAD.
c: Apparent hydrolysis coefficient in the second mesophilic stage in TPAD.

Sludge dewaterability after anaerobic digestion

After the determination of anaerobic sludge degradability, sludge dewaterability performance of the digested sludge was also assessed using a thermo-gravimetric method. In this test, water distributions in the digested sludge can be assessed by determining two critical points, one is free water content and the other is interstitial water. Table 4 shows water distributions in the digested sludge generated in the above described AD batch tests. Preliminary results showed that the content of free water in the digested sludge (with 2 days and 3 days SRT treated by three anaerobic processes) was approx. 7%, and the content of interstitial water was approx. 90%, indicating that solar drying could be a suitable dewatering method in practice. The sludge dewaterability for 4 days SRT sludge is being assessed at the moment.

Table 4. Water distribution in the digested sludge samples

	SRT	W_{free} (%)	$W_{interstitial}$ (%)	W_{bound} (%)
Mesophilic AD	2d	4.6	92.0	3.4
	3d	5.3	94.1	0.6
	4d	4.2	90.5	5.3
Thermophilic AD	2d	6.8	89.7	3.5
	3d	9.4	86.2	4.4
	4d	-	-	-
TPAD	2d	8.3	88.5	3.2
	3d	7.8	90.1	2.1
	4d	-	-	-

5. Overall progress of the project

Having project milestone 3 achieved as planned, the microbial analysis is undergoing to identify the microbial community structures in the SBR under each of the operation periods and the functional microorganisms mediating Bio-P removal. So far, the microbial communities in the SBR at 2 days, 3 days and 4 days SRT were studied using pyrosequencing analysis. Preliminary results showed that the microbial community structure changed during the initial 2 days SRT operation, especially some bacterial populations, which may be related to Bio-P removal, were enriched at the later stage. More interestingly, the classic organisms responsible for Bio-P removal, polyphosphate-accumulating organisms (PAOs), have not been detected in the 2 days SRT operation, which indicated that potentially as-yet-unknown PAOs may be involved in the observed Bio-P removal process. FISH and DAPI staining will be used together to identify the PAOs involved in this process.

The focus of the next stage of the project is to link up the two separate evaluated processes (high-rate aerobic treatment and anaerobic sludge digestion) together with a newly established Anammox-type process (for N removal in the sludge dewatering liquor) as one system under continuous conditions to form a treatment train for red meat processing effluent. The research plan and strategy have been developed and submitted separately to MLA as proposal for the next stage of the project.

The project operating expenses to June 2012 are outlined in Table 5. Cost for microbial analysis has substantially increased, as more samples were submitted for pyrosequencing analysis and FISH analysis has been started. Overall, the budget for the current financial year has been achieved as planned.

Table 5. Operating expenditure for period April-Jun 2012.

Description	Budget	Cost
Expenses	$12,000	$ 12,000
Total chemical analysis		$ 4400
Total microbial analysis		$ 5700
Other consumables & maintenance		$ 1270
Travel costs for wastewater collection		$ 630
Fees	$36,000	$36,000
TOTAL	**$48,000**	**$48,000**

6. Recommendations

- That this report be accepted as completion of Milestone 3 in Project A.ENV.0132.