SONICATED SLUDGE AS CARBON SOURCE FOR DENITRIFICATION

Michael Thomas [1], Pedro Rojas [1], Shaun Reynolds [1], Rodney Wellings [2]
1. Unitywater, Maroochydore, QLD, Australia
2. Royce Water Technologies, Brisbane, QLD, Australia

ABSTRACT

Ultrawaves sludge sonication technology was trialled at Maroochydore STP from February to June 2013. This was believed to be the first full-scale application of mechanical sludge lysis for enhanced denitrification in Australia. The results of the trial confirmed that sonicated waste activated sludge (WAS) could effectively replace the use of methanol as a carbon source for denitrification, and the use of one 5 kW Ultrawaves unit had a denitrification capacity of at least 57 kg N/d and reduced sludge production by about 100 kg/d.

INTRODUCTION

Ultrawaves sludge sonication technology was trialled at Maroochydore Sewage Treatment Plant (STP) from February to June 2013. The overall purpose of the trial was to provide a factual basis for a technical and economic feasibility study of Ultrawaves sludge sonication technology. The first objective of the trial was to determine if the use of sonicated waste activated sludge (WAS) could effectively replace the use of methanol as a carbon source for denitrification. Methanol is currently used, but it is expensive and is a hazardous chemical. The second technical objective was to assess whether sonication of WAS would decrease sludge production. This was important because sludge disposal accounts for almost 20% of the STP's annual operating costs. There was also a need to determine if the recycle of sonicated sludge back into the bioreactor would lead to an increase in aeration demand and blower power use as a result of the sonicated sludge being more biodegradable. The economic objective was to quantify the costs and benefits associated with the use of Ultrawaves units for enhanced denitrification to determine the whole-of-life cost.

METHODOLOGY

Operation of Sludge Sonication Unit

Sludge sonication has mostly been used for enhancement of anaerobic digestion, and only occasionally to replace external carbon sources required for denitrification. The application selected for Maroochydore STP was to replace methanol dosing, which is used for enhanced nitrogen removal. "Ultrawaves" sludge sonication technology was applied in Plant A Bioreactor at Maroochydore STP for 116 days between the months of February and June 2013 inclusive. An extended trial duration was necessary to collect valid data on changes in sludge production.

The unit was installed to process a partial sidestream of thickened waste activated sludge (WAS) from the dissolved air flotation (DAF) unit, which was used to thicken all WAS from both Plant A and Plant B bioreactors. A portion of the thickened WAS was pumped through the Ultrawaves unit, sonicated and returned to the Plant A Bioreactor. Therefore, additional daily WAS volume was required from Bioreactor A to compensate for the recirculation of thickened WAS via the Ultrawaves unit back into Bioreactor A.

The BNR process configuration for the bioreactors in both Plants A and B was 5-stage Bardenpho. This consisted of the following zones in series: anaerobic, anoxic, aerobic, de-aeration, anoxic, aerobic. During the trial sonicated thickened WAS was pumped from the Ultrawaves unit into the de-aeration zone of Plant A. This was intended to make optimum use of biodegradable COD, since part of the sonicated WAS would flow forwards into the secondary anoxic zone and part would be pumped back to the primary anoxic zone via the A-recycle pumps.

Immediately following the commencement of operation of the Ultrawaves unit the effluent nitrate concentration decreased to NO_x-N = 0.1 mg/L, and methanol dosing was turned off on 10 Feb 2013. Subsequently no methanol was required to be dosed to Plant A, although dosing was continued to Plant B for the duration of the trial.

The details of the operation of the Ultrawaves unit during the trial period are summarised below and all values presented are 50 percentile results for the duration of the trial period. Note that although the Ultrawaves unit operated on average 20 hr/d during the trial, the average downtime of 4 hr/d mostly reflected the downtime of the DAF unit and other components of the sludge process at Maroochydore STP.

- Number of Ultrawaves units used in trial = 1
- Rated power per unit = 5 kW
- Operating power per unit = 3.5 kW
- Ultrasonic operating frequency = 20 kHz
- Operating hours per day = 20.6 hr/d
- Power consumption = 76 kWh/d
- Working volume of unit = 30 L
- Daily volume of thickened WAS to unit = 25 m^3/d
- Thickened WAS flow rate to unit = 1.2 m^3/hr = 0.33 L/s
- Hydraulic residence time in unit = 90 sec
- Thickened WAS concentration = 3.8%TS = 38 kg/m^3
- Thickened WAS mass loading rate to unit = 45 kg TS/hr
- Daily mass of thickened WAS to unit (and recycled to Bioreactor A) = 870 kg/d
- Daily mass of thickened WAS from Bioreactor A to digester = 1735 kg/d
- MLSS solids inventory in Bioreactor A = 30,700 kg
- Fraction of Bioreactor A solids inventory exposed to daily sonication = 2.8% per day
- Fraction of Bioreactor A WAS exposed to daily sonication and recycled = 50%
- Fraction of total plant WAS exposed to daily sonication = 18%
- Specific volumetric ultrasonic energy input = 3.0 kWh/m^3
- Specific ultrasonic energy input per kg dry solids = 0.078 kWh/kg (dry solids)
- Temperature increase of WAS due to absorbance of ultrasonic energy = 2.8°C.

It was interesting to note that the ultrasonic energy input used by the Ultrawaves technology is significantly lower than most applications reported in research literature, with many research investigations carried out with specific energy inputs that were 10 times higher than adopted in the Ultrawaves technology (e.g. Ek (2005), Muller (2006), Appels et at (2008), Zhang (2010), Yan et al (2010), Demir et al (2013)). This is an important aspect of the Ultrawaves technology that reduces energy requirements and improves its economics.

Plant Configuration During Trial

An overview of the liquid and solids process streams at Maroochydore STP is outlined below and in Figure 1. The liquid process stream is based around a BNR activated sludge process with some enhancements and it was comprised of the following process units:

- Inlet band screens and vortex grit tanks
- Side-stream flow balance tank
- Primary sedimentation tanks
- Primary sludge fermenters
- 5-stage Bardenpho BNR bioreactors (i.e. anaerobic-anoxic-aerobic-anoxic-aerobic)
- Alum dosing for P removal
- Methanol dosing for denitrification because bioreactors are COD-limited due to removal in primary sed tanks
- Secondary clarifiers
- Disk cloth filters
- Ultraviolet (UV) disinfection

The solids process stream was comprised of the following process units:

- Rotary screen thickeners for waste fermented primary sludge
- Dissolved air flotation for waste activated sludge
- Anaerobic digesters
- Dewatering centrifuge
- Biosolids solar dryer

This evaluation was based on comparing the results obtained in Plant A and for the whole Maroochydore STP, with and without the Ultrawaves sludge sonication technology. Data from a "baseline" period from Jun 2012 to Jan 2013 inclusive was used to compare with data from the "trial" period of Feb to Jun 2013 inclusive.

The design of Maroochydore STP was based on one third of the total influent flow and load to be treated in Plant A. However, the design allows flexibility for this load split to be modified from time to time e.g. for maintenance, and this was the case for many months during the baseline period. Therefore, when evaluating the data, it was necessary to sub-divide the baseline period into 2 phases. The first phase of the baseline period from Jun to Jul 2012 had the same flow split as the trial period, whereas the second phase of the baseline period from Aug 2012 to Jan 2013 had a higher flow split to Plant A than normal (Table 1). Approximately 44% of the total influent load was treated by Plant A during the baseline period, whereas during the trial Plant A treated 35% of the total influent load. In both cases, the balance of flow and load was treated in Plant B.

The influent results for the trial and baseline periods are presented in Table 2. The timing of the trial coincided with the wet season and consequently during the trial the influent was diluted compared to the baseline. Recorded rainfall was 1044 mm during the 8 month baseline period compared to 1328 mm during the 5 month trial period. Despite the average flow treated by Plant A being quite similar for both periods: 11.30 ML/d during the baseline and 11.45 ML/d during the trial; the pollutant mass loads treated by Plant A were lower during the trial than during the baseline.

All analytical testing was performed by the Unitywater NATA-accredited lab using Standard Methods.

RESULTS AND DISCUSSION

Denitrification Capacity and Elimination of Methanol

Low nitrate (NO_X-N) values for treated effluent were recorded during the trial period (Table 3) without methanol dosing, which demonstrated the effectiveness of sludge sonication for achieving full denitrification in Bioreactor A. This confirmed that the sonicated WAS provided biodegradable COD for denitrification. There were occasional spikes in effluent NO_x-N during the trial (data not shown), which were mainly the result of short-term stoppages of the Ultrawaves unit due to no availability of thickened WAS, which was caused by equipment failures elsewhere in the solids process.

The difference in effluent TSS and turbidity results between the baseline and trial periods was of no material significance (Table 3). This indicated that any ruptured flocs arising from sludge sonication were either re-flocculated into the biomass and/or biodegraded, and did not escape into the effluent.

During the whole baseline period before the trial, when methanol was dosed to both Bioreactors A and B, the total usage averaged 975 L/d. During the trial the methanol use in Bioreactor B was 712 L/d, which superficially represents a saving of approximately 263 L/d of methanol. However, total plant load increased from equivalent to 98,000 EP during baseline to 102,000 EP during the trial, and the fraction of load treated by Plant B was higher during the trial. Therefore, the methanol use during the trial needs to be normalised to align with conditions during the baseline period.

One final stage of experimental data collection occurred after the Ultrawaves trial ended. Plant A Bioreactor was operated without methanol and without recycle of sonicated WAS from beginning July to 11 Aug 2013 with the same influent load split that was operating during the trial. The results indicate that the average effluent NO_X-N was 5 mg/L if no external source of carbon was used for denitrification in Plant A. There was a degree of variability in Plant A denitrification performance during this final experimental period with no external carbon source, and effluent NO_x-N results varied between 3 and 8.5 mg/L. This was probably as result of variability in the existing internal sources of carbon such as fermenter supernatant and fermented sludge thickening filtrate.

There were also 9 days during the trial when there were effluent NO_x-N spikes > 3 mg/L, and of these occasions, 5 days were when the Ultrawaves unit was switched off and for these days the 50%-ile effluent NO_x-N was 5.0 mg/L. This further confirmed how much nitrate was typically being removed by the recycled of sonicated WAS during the trial. Furthermore it was noted that the on-line nitrate analyser located immediately upstream of the post-anoxic zone (trial location) typically recorded 5 to 10 mg N/L. Therefore, these results confirm that nitrate removal in the post-anoxic zone was typically at least 5 mg/L using either methanol or sonicated WAS as the carbon source.

Soluble COD before and after the Ultrawaves unit was measured intermittently during the trial. Although it wasn't possible to make a reliable measurement of the rate of conversion from particulate to soluble COD through the Ultrawaves unit, the available data was used to estimate the total COD returning to the Bioreactor A was 850 kg COD/d (Table 4). Although the results were variable, the mass of soluble COD recycled with the sonicated WAS averaged 5 kg COD/d.

The three main observations related to nitrogen removal were reviewed for consistency:

1. Nitrate removal of 5 mg/L corresponded to a mass of 57 kg N/d under the trial flow conditions. The amount of COD required to remove 57 kg N/d depends on the thermodynamics of growth with that substrate, which dictates the biomass yield for growth on each type of substrate. Consequently, the stoichiometric ratio of COD required to NO_3-N removed varies with different carbon sources.
2. Reduction in methanol use of 263 L/d corresponded to COD = 304 kg/d. The typical stoichiometric denitrification ratio for methanol is 3 kg COD/kg N, which indicates that the methanol could have had the potential to remove up to 101 kg N/d. Under the trial flow conditions (= 11.45 ML/d), then 101 kg N/d was equivalent to 8.8 mg N/L of potential nitrate removal. Furthermore, the amount of methanol required to remove 57 kg N/d was 171 kg COD/d, which is equivalent to about 150 L/d. These results indicate that there may have been competing reactions for the methanol, although it was confirmed that there was no oxygen input to the post-anoxic zone, or that methanol over-dosing occurred, or that the concentration of nitrate removed was closer to 8 mg/L than 5 mg/L.
3. COD of recirculated sonicated WAS = 850 kg/d, including soluble COD = 5 kg/d. Although the degree of biodegradability of the sonicated WAS was unknown, it is known that extra-cellular polymers in activated sludge are predominantly proteins (or polypeptides) and sugars (or polysaccharides), which are somewhat similar to the typical compounds expected to be present in sewage. The typical stoichiometric denitrification ratio for sewage is 8.6 kg COD/kg N, which indicates that the sonicated WAS could have had the potential to remove up to a maximum of 99 kg N/d if it was completely biodegradable. Under the trial flow conditions (= 11.45 ML/d), then 99 kg N/d is equivalent to a maximum potential nitrate removal of 8.6 mg N/L. Whereas the soluble

COD in the sonicated WAS would have had the potential to removed less than 1 kg N/d. Furthermore, the amount of typical sewage-COD required to removed 57 kg N/d is 490 kg COD/d. These results indicate that at least 60% of the COD in the sonicated WAS must have been biodegradable, and that the soluble COD in the sonicated WAS played a minor role in denitrification.

The supplier's hypothesis that sludge sonication results in significant conversion of particulate sludge to soluble COD was only partly supported by results from this trial. An hypothesis consistent with the trial results was that sonication of waste activated sludge caused rupture of the flocs (as opposed to the bacterial cells) and release of extra-cellular polymer compounds, and that these were the source of biodegradable COD for denitrification.

Reduced Solids Production

Sludge production before and after digestion for the baseline and trial periods was evaluated using available data to develop a solids mass balance (Table 5). However, since "steady-state" conditions did not occur continuously (which is "normal" for full-scale plants), and there were changes in the total and relative pollutant loads treated by Plant A, three sludge production indicators were reviewed.

The solids production before digestion was higher during the trial period, which was in line with the higher loads treated by the plant e.g. additional tanker septage wastes. It was noted that the mass of volatile solids (VS) before digestion was the same during both the baseline and trial periods (4200 kg/d) (Table 5). Therefore, the lower mass of volatile solids post-digestion during the trial period confirmed that ultrasonic treatment of the sludge provided benefits of decreased sludge production. The benefit derived from one Ultrawaves unit was estimated to be 140 kg/d of additional VS destruction using the mass balance, which was equivalent to 14% increase in VS destruction, from 22% during the baseline to 25% during the trial. Note that this was relatively poor performance for anaerobic digestion.

The second indicator was specific sludge production normalised relative to Equivalent Population (EP). The results were 48 g TS/EP/d during the Ultrawaves trial compared to 51 g TS/EP/d produced when methanol was used during the baseline (Table 5), which was equivalent to 6% additional solids destruction.

The third indicator was volatile solids (VS) production normalised relative to COD load (Table 6). The observed sludge yield for the whole plant **before** digestion was 4% lower during the trial (0.45 kg VS/kg COD) compared to the baseline (0.47 kg VS/kg COD). Whereas the observed sludge yield for the whole plant **after** digestion was 10% lower during the trial (0.37 kg VS/kg COD) compared to the baseline (0.41 kg VS/kg COD). This was interpreted to mean that following sonication of the WAS, 4% of the volatile solids were converted to carbon dioxide (CO_2) in the bioreactor, and a further 6% was converted to biogas in the anaerobic digesters.

In summary, within the accuracy and variability of the data, a potential benefit of approximately 10% additional volatile solids destruction (equivalent to 100 kg/d) can be attributed to sonication of WAS with one Ultrawaves unit.

Effect on Aeration Demand

The effect of recycling sonicated, biodegradable sludge back into Plant A bioreactor was analysed to determine whether aeration demand was increased based on air flows and power consumption of the blowers. The results for the aeration system are summarised in Table 7. Due to the differences in influent loads and aeration demands when comparing the baseline and trial periods, it was necessary to normalise aeration system performance.

The actual blower power (kWh) per kg O_2 transferred was the same across the two periods = 0.27 kWh/kg O_2. The ratio of oxygen supply to oxygen demand (carbonaceous plus nitrogenous) was practically the same between the 2 periods = 1.05 - 1.06 kg O_2 supply / kg O_2 demand. Blower power and air flows were normalised relative to the total COD treated in the Bioreactor (including recycles, fermenter supernatant and RST filtrate). The specific blower power consumption was the same in both the baseline and trial periods (0.21 kWh/kg $COD_{influent}$), and the specific blower oxygen supply was also virtually the same in both the baseline and trial periods (0.79 - 0.80 kg O_2/kg $COD_{influent}$).

Finally, the COD mass balance clearly shows that the fraction of COD that was oxidised aerobically did not increase as a result of recycling sonicated, biodegradable sludge into Bioreactor A (Table 4). Therefore, the additional load of sonicated WAS that was recycled to the bioreactor did not increase air demand or blower power use.

Economic Analysis

A cost benefit analysis was performed to evaluate the whole-of-life cost for the scenario where Ultrawaves units were installed to enhance denitrification for both Bioreactors A and B at Maroochydore STP. The net present value (NPV) was calculated using an interest rate of 7.7% p.a. for a duration of 18 years ending in 2031, which is the assumed planning horizon for closure of Maroochydore STP and also aligns with the expected life of mechanical equipment. Over this time frame the equivalent population (EP) served by the plant is expected to grow from 100,000 EP to

135,000 EP. The capex and opex components used for the cost benefit analysis are itemised below and were derived from outcomes of the trial wherever possible. The CAPEX and OPEX components for 5 kW Ultrawaves units are listed in (Table 8) and all cost exclude tax (GST).

Four Ultrawaves units would be required initially and would have sufficient capacity for enhanced denitrification for about 110,000 EP within the existing operating configuration of Maroochydore STP. However, this assumed no redundant Ultrawaves units are provided and would be dependent on local availability of spare parts, and/or using the existing methanol dosing system in the event of one or more Ultrawaves units being out-of-service. A fifth Ultrawaves unit would need to be installed when the population in the STP service area increases to about 110,000 EP.

The main OPEX benefits quantified during the trial were the saving in methanol consumption and lower sludge production.

- Saving from reduced methanol use for 100,000 EP = 995 L/d x 0.77 kg/L x $640/T x 365 d/yr = $178,973/yr annual expenditure increasing with EP growth. NPV = + $1,941,610.
- Saving from reduced sludge production for 100,000 EP = 90 kg VS/d x 4 units @ 45%TS dryness x $60/wet T x 365 d/yr = $17,520/yr annual expenditure increasing with EP growth. NPV = + $186,408.

The cost benefit analysis derived from the outcomes of this trial showed a positive balance for NPV:

- OPEX savings = + $2,128,017;
- Ultrawaves CAPEX and OPEX = - $1,609,147;
- Net Present Value = + $518,870.

It is important to note that the Ultrawaves CAPEX excludes installation costs, but as long as it was less than $500,000 then the NPV remains positive. Furthermore, cost benefit details presented above were for the “worst case” scenario. When the following factors were adjusted in a sensitivity analysis then the financial benefit becomes more financially favourable than presented above:

- If trials under conditions that are not nitrate-limited can demonstrate that the nitrogen removal capacity of one Ultrawaves unit is significantly greater than 57 kg N/d, such that one less Ultrawaves unit would be required, then the NPV of the CAPEX would improve from - $805,312 to - $641,910.
- Sonitrode replacement frequency was assumed to be every 18 months, but service life has been observed to be up to 2 years. Similarly, booster shaft replacement frequency was assumed to be every 3 years, but service life has been observed to be up to 4 years. If the “best case” replacement parts life was adopted, then the NPV of the Ultrawaves OPEX would improve from - $580,146 to - $463,455.
- If volatile solids destruction of 140 kg/d per unit is achieved rather than 90 kg/d per unit, then the NPV of the OPEX savings for biosolids transport would improve from + $186,408 to + $289,967.

CONCLUSION

The first full-scale application of sludge sonication for enhanced denitrification was successfully demonstrated at Maroochydore STP. One 5 kW Ultrawaves unit had a denitrification capacity of at least 57 kg N/d and reduced sludge production by about 100 kg/d. The resulting OPEX savings indicated that the whole-of-life cost for a full-scale installation would be cost positive. Although widely used for sludge pre-treatment for anaerobic digestion, sonication has the potential to achieve high levels of nitrogen removal in plants with primary sedimentation at a lower cost than methanol dosing.

ACKNOWLEDGMENT

The efforts and input from Dr Klaus Nickel, all Maroochydore STP Operations staff, and Luisa Magalhaes for this trial were greatly appreciated.

REFERENCES

Appels, L., Dewil, R. and Baeyens, J. (2008). Ultrasonically enhanced anaerobic digestion of municipal sewage sludge, Int Jnl Sust Eng, Apr 2008.

Demir, O., Erden, G. and Filibeli, A. (2013). The methods for minimization of excess sludge production, proceedings of ICOEST conference 2013, Nevsehir, Turkey, 18-21 Jun 2013.

Ek, A. (2005). Ultrasonic treatment of sewage sludge in order to increase biogas yields, PhD dissertation, Linkoping University, Sweden, Jun 2005.

Muller, C.D. (2006). Shear forces, floc structure and their impact on anaerobic digestion and biosolids stability, PhD dissertation, Virginia Polytechnic Institute and State University, USA, Jul 2006.

Yan, Y., Feng, L., Zhang, C., Zhu, H. and Zhou, Q. (2010). Effect of ultrasonic specific energy on waste activated sludge solubilization and enzyme activity, African Jnl Biotech, Vol.9 (12), pp. 1776-1782, 22 Mar 2010.

Zhang, H.J. (2010). Sludge treatment to increase biogas production, Degree Project 10-20 dissertation, Royal Institute of Technology, Sweden, Aug 2010.

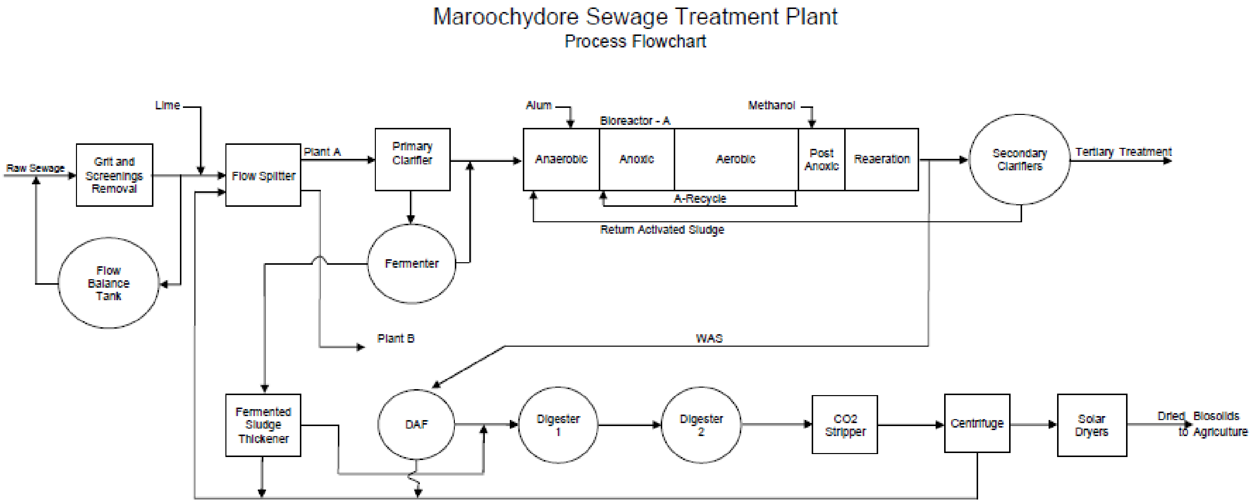

Figure 1: Maroochydore STP Process Flowchart (Plant B liquid process not shown)

Table 1: Flow Split to Plant A During Trial and Baseline Periods

Period	**Flow Fraction to Plant A**
Baseline Phase 1 (Jun – Jul 2012)	35%
Baseline Phase 2 (Aug 2012 – Jan 2013)	55%
Entire Baseline Period (Jun 2012 – Jan 2013)	44%
Trial Period (Feb – Jun 2013)	35%

Table 2: Raw Sewage Characteristics and Mass Loads to Plant A

Parameter	**Baseline June 2012 – January 2013**			**Trial February – June 2013**		
	Conc. mg/L	Total Load kg/d	Plant A Load kg/d	Conc. mg/L	Total Load kg/d	Plant A Load kg/d
COD	475	12,165	5350	400	13,084	4580
BOD	195	4995	2200	160	5234	1830
TSS	250	6400	2820	200	6542	2290
VSS	191	4890	2150	149	4874	1710
%VS/TS	76	-	-	75	-	-
TKN	50	1280	564	40	1308	458
NH3N	35	900	394	31	1014	355
COD/TKN	9.5	-	-	10.0		
Flow	-	25.61 ML/d	11.27 ML/d	-	32.71 ML/d	11.45 ML/d

Table 3: Plant A Treated Effluent Results (50 percentile)

Period	**BOD_5** (mg/L)	**TSS** (mg/L)	**NH_3-N** (mg/L)	**NO_x-N** (mg/L)	**TN** (mg/L)	**PO_4-P** (mg/L)	**TP** (mg/L)	**TDS** (mg/L)	**TURBIDITY** (NTU)
Jun 2012-Jan 2013	<5	9	0.1	1.5	3.6	0.10	0.20	1000	5
Jun-July 2012 only	2	15	0.1	2.5	3.3	0.10	0.20	800	5
Feb-Jun 2013	<5	6.5	0.1	0.1	1.7	0.10	0.15	900	11

Table 4: COD Mass Balance for Plant A Bioreactor

Bioreactor Inputs and Outputs	**Baseline Jun 12-Jan 13 (kg COD / d)**	**Trial Feb 13-Jun 13 (kg COD / d)**
Primary effluent and fermenter supernatant COD into Bioreactor A	5466	5201
Methanol COD into Bioreactor A	304	0
Recycled sonicated WAS	0	850
Total Influent COD to Bioreactor A	5770	6051
WAS (net WAS excl. recycled WAS and primary sludge)	1847	1689
COD for Denit.	1004	902
COD aerobic oxidation	2524	2210
Effluent COD	394	401
Fraction of primary effluent COD oxidised aerobically	46%	42%
Fraction of total influent COD oxidised aerobically	44%	37%

Table 5: Sludge Production Results for Whole Plant

Sludge production before digestion (whole STP)		
Parameter	Baseline June 2012 – January 2013	Trial February – June 2013
Thickened sludge flow (kL/d)	171	183
TS (kg/d)	5740	5965
VS (kg/d)	4236	4224
Inert solids (kg/d)	*1504* [1]	1741
%VS/TS	74	71
Fraction of primary / total sludge (%)	26	18
HRT (d) (Digester 1 & 2 combined)	18	17
Sludge production post-digestion (whole STP)		
TS (kg/d)	5021	4889
VS (kg/d)	3301	3149
Inert solids (kg/d)	*1720* [1]	1740
%VS/TS	66	64
Specific digested sludge production (g TS/EP/d)	51	48
Digestion Efficiency: Volatile Solids Reduction		
Volatile solids destruction (kg/d)	935	1075
Total solids destruction (kg/d)	*719* [1]	1076
Calculated using van Kleeck equation	*32%* [1]	25%
Calculated using mass balance	22%	25%
Additional VS destruction during trial compared to baseline period		+140 kg/d

Note 1: The average values used for the mass balance during the baseline period show that inert solids were not conserved. This was likely to be a consequence of averaging a data-set that was highly variable due to the operating conditions not being "steady-state" over the baseline period. The consequence was that there were discrepancies such that the total solids destruction was less than the volatile solids destruction, and errors in the VS destruction calculated by the van Kleeck equation.

Table 6: Observed Sludge Yield for Maroochydore STP

Observed Sludge Yield (kg VS / kg COD)	**Baseline Jun 2012 – Jan 2013**	**Trial Feb – Jun 2013**
Sludge produced before digestion (whole plant kg VS/kg COD raw sewage)	0.47	0.45
Sludge produced after digestion (whole plant kg VS/kg COD raw sewage)	0.41	0.37

Table 7: Plant A Aeration System Performance

Parameter	Units	Baseline (entire period) Jun 12-Jan 13	Baseline (reduced period) Jun 12-Jul 12	Trial Feb 13-Jun 13
Raw sewage COD load	kg COD/d	5350	- [2]	4580
Raw sewage BOD load	kg BOD/d	2200	- [2]	1830
Raw sewage NH_3-N load	kg N/d	394	- [2]	355
Equivalent O_2 demand (= BOD + 4.57 * NH_3-N)	kg O_2/d	4001	- [2]	3452
Blowers daily air flow	Nm^3/d	106,125	75,457	92,307
Oxygen supply transferred (calculated from air flow)	kg O_2/d	4203	2989	3656
Nitrification oxygen demand	kg O_2/d	1679	-	1446
Aerobic COD oxidation oxygen demand	kg O_2/d	2524	-	2210
COD oxidation / total O_2 demand	%	60%	-	60%
Oxygen supply / Equivalent O_2 demand	kg O_2 supply / kg O_2 demand	1.05	-	1.06
Oxygen supply transferred / influent COD load	kg O_2 / kg COD	0.79	-	0.80
Blowers daily power use	kWh/d	1124	937	977
Blower power use for oxygen transfer	kWh/kg O_2 supply	0.27	0.31	0.27
Blower power use relative to influent COD load	kWh/kg COD	0.21	-	0.21

Note 2: Raw sewage results during this period were not representative due to sampling error.

Table 8: Ultrawaves Unit CAPEX and OPEX Components (excl. GST)

CAPEX	**Unit Cost**	**Number of Units**	**Frequency of expenditure**	**NPV**
Ultrawaves units	\$176,000 / unit	4 units for 100,000 EP	One-off at year 2014	
Ultrawaves units	\$176,000 / unit	5^{th} unit at 110,000 EP	One-off at year 2021	**- \$805,312**
OPEX	**Unit Cost**	**Annual Cost**	**Frequency of expenditure**	**NPV**
Power	120 kWh/d / unit x \$0.12/kWh	\$5,256/yr / unit	Every year, with total annual cost dependent on number of units installed	**- \$223,689**
Maintenance parts	5 Sonitrodes / unit x \$2,250	\$11,250/yr / unit	Every 18 months i.e. twice per 3 yr	**- \$392,845**
Maintenance parts	5 Booster shafts / unit x \$1,740	\$8,700/yr / unit	Every 3 years	**- \$187,300**