4A-110: *Integrated wastewater treatment plant* (iWWTP) *data collection (January – April 2019)*

Report prepared for the
The Australasian Pork Research Institute Ltd.
And
Co-operative Research Centre for High Integrity Australian Pork

By

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EXECUTIVE SUMMARY

This report is an adjunct to the report submitted for project *4a-105 - Aerobic and algal treatment of piggery wastewaters for heat recovery, effluent treatment and water reuse* by Fallowfield and Cheng (2018) and provides additional data requested to meet the original project milestones.

The data were collected over a period of 3 months between January and April 2019.

The integrated wastewater treatment pilot plant constructed at Roseworthy Piggery comprises of an anaerobic pond, an aerobic reactor and a high rate algal pond operated in series. The $10m^3$ aerobic reactor (AR) was operated to maintain a dissolved oxygen concentration of 3 – 4 mg O_2 L^{-1} (the setpoint) at theoretical hydraulic retention times (THRT) of 5d and 10d.

The DO setpoint (3 – 4 mg O_2 L^{-1}) was maintained over a period of 28d at a THRT 10d. This duration is approaching that required to achieve steady state (3 THRT i.e. 30d). Under these conditions the aerobic reactor achieved >50% total suspended solid reduction, high rates of nitrification and a 50% reduction in ammonium concentration.

Greater than 60% of the total carbon in the aerobically treated effluent was in the form of inorganic carbon comprised. Indicating there was sufficient mineralizable organic carbon available in the anaerobically pre-treated effluent to 'drive' nitrification in the aerobic reactor and also sufficient for algal growth and photosynthesis in the HRAP.

At steady state, operated at a mixed liquor volume of $10m^3$ at a 10d THRT and a DO setpoint of 3 – 4 mg O_2 L^{-1}, the calculated energy consumption for aeration was 2.53 kW d^{-1}. Heat from the submerged aerator was recovered, together with metabolic heat and radiant energy into the aerobic reactor mixed liquor. The temperature of the aerobic reactor mixed liquor was 9^0C above ambient air temperature offering the potential to recover energy as hot water for piggery operations by using a heat exchanger and heat pump. However, aerobic treatment of raw slurry, which releases more metabolic energy, with heat recovery is likely to be the more economic approach and is worthy of future research.

An algal inoculum was readily established in the HRAP operated at 0.3m depth using 5% (v/v) of the effluent from the aerobic reactor operated at a 10d THRT and a DO setpoint of 3 – 4 mg O_2 L^{-1}.

This inoculum (1.21 mg chlorophyll *a* L^{-1}) was then used in a trial conducted over 20d using 10% (v/v) aerobic reactor effluent containing < 100 mgNH_4-N L^{-1}. Algal biomass determined as chlorophyll *a*, TSS or POC was initially maintained in the culture, however, there was an unexpected steady decline in all biomass parameter towards the end of the trial period. The decline was *unlikely* due to ammonia toxicity since the ammonium concentration was < 100 mg L^{-1}. The decline in algal biomass was when rates of nitrification were high the decline in algal biomass was possibly due to competition between nitrifying bacteria and algae for inorganic carbon during the period of increased nitrification. Light availability for algal photosynthesis may also have influenced the decline. Light availability is affected by wastewater colour and suspended solids and by the algal biomass. The initial inoculum may

have been too concentrated reducing light availability culture due to ‘self-shading’ of algal cells and while it maintained, growth could not occur under the imposed culture conditions.

The microbiological quality of the wastewater was improved significantly following treatment of the anaerobic pond effluent by the integrated aerobic-algal system. Overall there was a 3 log_{10} reduction in *E.coli* numbers following integrated treatment. *E.coli* is a recognised treatment performance indicator and is also used as a surrogate for the behaviour of bacterial pathogens. The availability of higher quality wastewater for reuse has the potential to improve pig health, decrease the time to slaughter weight and reduce associated feed costs. Further research on pathogen and ammonia removal by the integrated treatment system is recommended with the objective of improving the production environment and pig health. Research on the behaviour of multiple antibiotic resistant bacteria in the integrated system is also warranted.

A second growth trial was conducted using 50% (v/v) aerobic reactor effluent. The chlorophyll *a* concentration of this inoculum was a third that used in the previous 20d trial. Time constraints meant that this culture could only be operated for 7 day. Algal growth in this effluent was clearly demonstrated, evidenced by increases in chlorophyll *a*, total suspended solids and particulate organic carbon concentrations. NO_3-N was the nitrogen source for growth.

The Roseworthy integrated wastewater treatment system is a durable research asset to the pork industry. Further research is warranted on the integrated system with regards to ammonium and pathogen removal in wastewater destined for reuse with the objective of improving the quality of the production environment, pig health and the economics of pork production.

1 INTRODUCTION

Program 4 *Carbon Conscious Nutrient Inputs and Outputs* of the Pork CRC aimed to reduce effluent emissions through novel management strategies. This included research on the potential for algal biotechnology to contribute to meeting the aspirational target to reduce greenhouse gas emissions (GHG) from 6-8 kg CO_2e kg meat^{-1} to 1 kg CO_2e kg meat^{-1} for at least 5% of meat produced. Following, a comprehensive review[1] wastewater treatment, capable of integration with current practice was identified as the most likely approach to integrate the potential for algal biotechnology to meet these objectives.

The rationale for this project, the design and construction of the plant have been presented in detail elsewhere[2]. Briefly, anaerobic lagoons are the predominant treatment systems employed within the Australian pork industry. The effluent is reused within the production environment. It is generally of poor quality containing high concentrations of ammonia and potentially pathogenic microorganisms. The combination of high ammonia and pathogens has been shown to have an adverse effect on pig health (Murphy *et al.*, 2012); potentially increasing the time and associated feed costs to achieve slaughter weight.

Algae grow prolifically, in suitable wastewaters while using carbon dioxide derived from the microbially oxidation of the organic matter within the wastewater. The algal biomass can be converted on-site to energy, off-setting CO_2 emissions from fossil fuel derived electricity and reducing GHG emissions. High concentrations of ammonia inhibit algal growth. Aerobic treatment of effluent from anaerobic lagoons was identified as a technology, which could convert ammonia into nitrate removing its adverse impact on both pig health and algae.

The integration of anaerobic - aerobic - algal treatment of piggery wastewater was investigated at Roseworthy Piggery, Adelaide. A pilot plant was constructed which received anaerobically treated effluent from an existing lagoon. The effluent was treated in a13m^3 nitrifying aerobic reactor. The nitrified effluent was supplied to a 59m^2, (19 m^3) high rate algal pond operated at 0.3 m depth for nutrient removal and disinfection. The pilot plant is capable of remote operation and was also monitored remotely using cloud-based software.

Unfortunate delays in receiving permissions, concluding leasing agreements and ultimately in construction significantly reduced the time over which research could be conducted. The report to the Pork CRC by Fallowfield and Cheng (2018) described the commissioning of the pilot plant and the characterisation of the aerobic reactor; demonstrating its potential for nitrification.

The Pork CRC requested additional research be performed to address the outstanding milestones prescribed for the original project. This report addresses those milestones, namely:

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[1] Buchanan, AN, Bolton, N, Moheimani, N, Svoboda, IF, Grant, T, Batten, D, Cheng, NN, Borowitzka, M, and Fallowfield HJ. (2013) *Algae for energy and feed: a wastewater solution. A review;* pp203, High Integrity Australian Pork CRC.

[2] Fallowfield and Cheng (2018) *4a-105 - Aerobic and algal treatment of piggery wastewaters for heat recovery, effluent treatment and water reuse; pp38, High Integrity Australian Pork CRC.*

Milestone 1 HRAP operation conditions determined to maximise algal biomass energy production and disinfection of water for reuse in piggery operations. Evaluation of the performance of the iWWTP

Milestone 2: Final report preparation and submission

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2 GENERAL MATERIALS AND METHODOLOGY

2.1 Operational overview - configuration and experimental set up

Roseworthy Piggery, University of Adelaide (34°30’45.62”S, 138°40’43.85”E; Plate 2.1 & 2.2), after consultation with industry and the Pork CRC, was selected as the site for the Flinders University research facility – integrated wastewater treatment pilot plant. The research pilot plant was constructed comprising a $13m^3$ aerobic reactor with a 1.1 kW aerator. Aeration, to convert ammonia to nitrate, is controlled by continuous monitoring of dissolved oxygen to reduce energy consumption. The aerobic treatment is followed by nutrient removal and disinfection in a $59m^2$, $19m^3$ at 0.3 m depth high rate algal pond (HRAP). The HRAP is a single pass raceway, with a maximum operational depth of 0.5m, mixed by a paddlewheel powered by a 0.75 kW motor and gearbox. The pilot plant is operated and monitored remotely using cloud based software.

Plate 2.1 Roseworthy Piggery (right) showing anaerobic lagoon (top left) and adjacent pilot site for integrated aerobic-algal wastewater treatment (down, left side across the road) by Google Maps and Google Earth imagery data @ 2019. The HRAP can be visually seen as green from the satellite imagery.

Plate 2.2 The integrated aerobic-algal wastewater treatment facility

Anaerobically digested piggery effluent from the existing anaerobic lagoon (from Roseworthy piggery) is firstly transferred to a reception pit (Fig.2.1, T1) and then to the aerobic reactor at programmed intervals. NH_3-N is converted to NO_3–N under aerobic conditions using naturally occurring populations of aerobic nitrifying bacteria. The resulting treated slurry is then pumped into a sedimentation tank (T2) where the supernatant liquid phase is delivered to a make-up tank (T3). Finally, effluent from the makeup tank is transferred into HRAP for nutrient removal via growth of the algal biomass. The HRAP is mixed by an eight bladed paddlewheel and its hydraulic residence time is determined by the rate of slurry addition and/or change in HRAP depth (maximum operating depth 0.5m). A single, earthen walled HRAP with a base surface area of 59 m^2, lined with geotextile and 1.5mm HDPE liner was constructed. The HRAP volume is 19m^3 at an operational depth of 0.3m. The concrete channel divider and a concrete mounting block supported an 8 blade stainless steel paddlewheel, driven by a 0.75 kW motor coupled directly to a 1:100 reduction gear box with shear pin. The paddlewheel was designed to rotate at about 12 rpm to provide a mean surface velocity of 0.2 m s^{-2}. Treated HRAP effluent is returned to sump (T4) and then returned to anaerobic pond prior to land spreading (Figure 2.1 & 2.2).

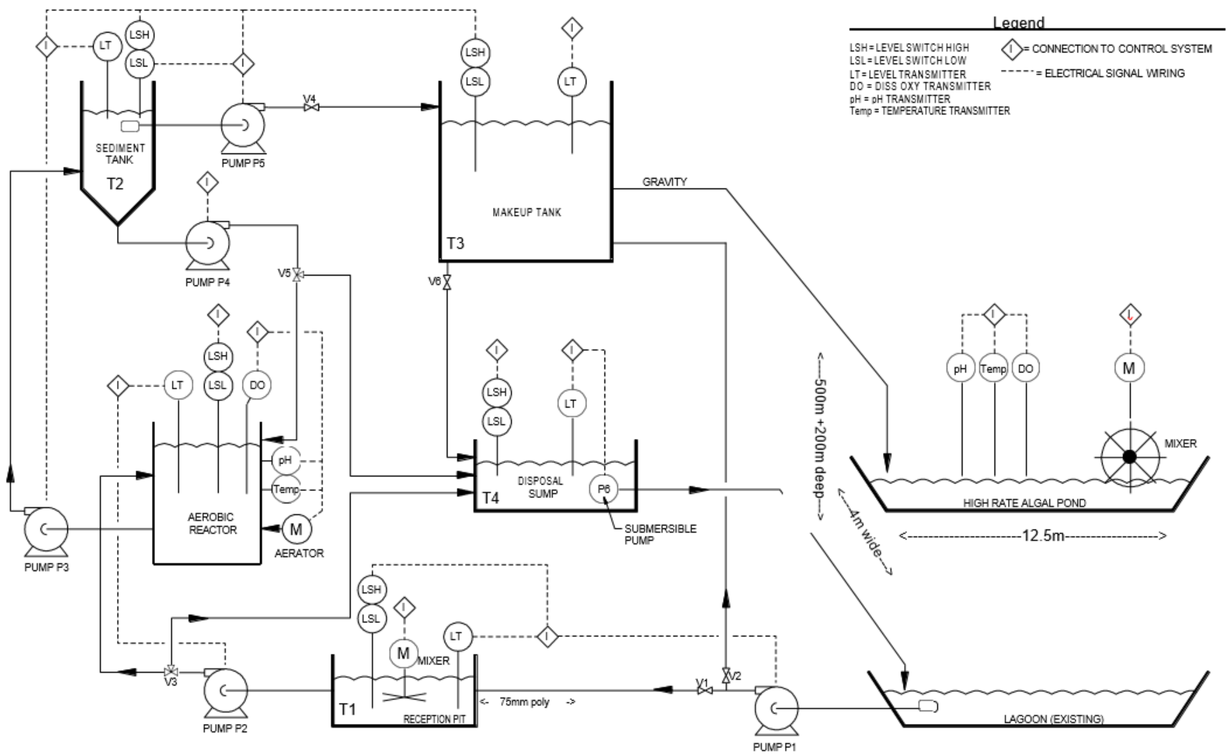

Figure 2.1 Schematic of control of integrated wastewater treatment system.

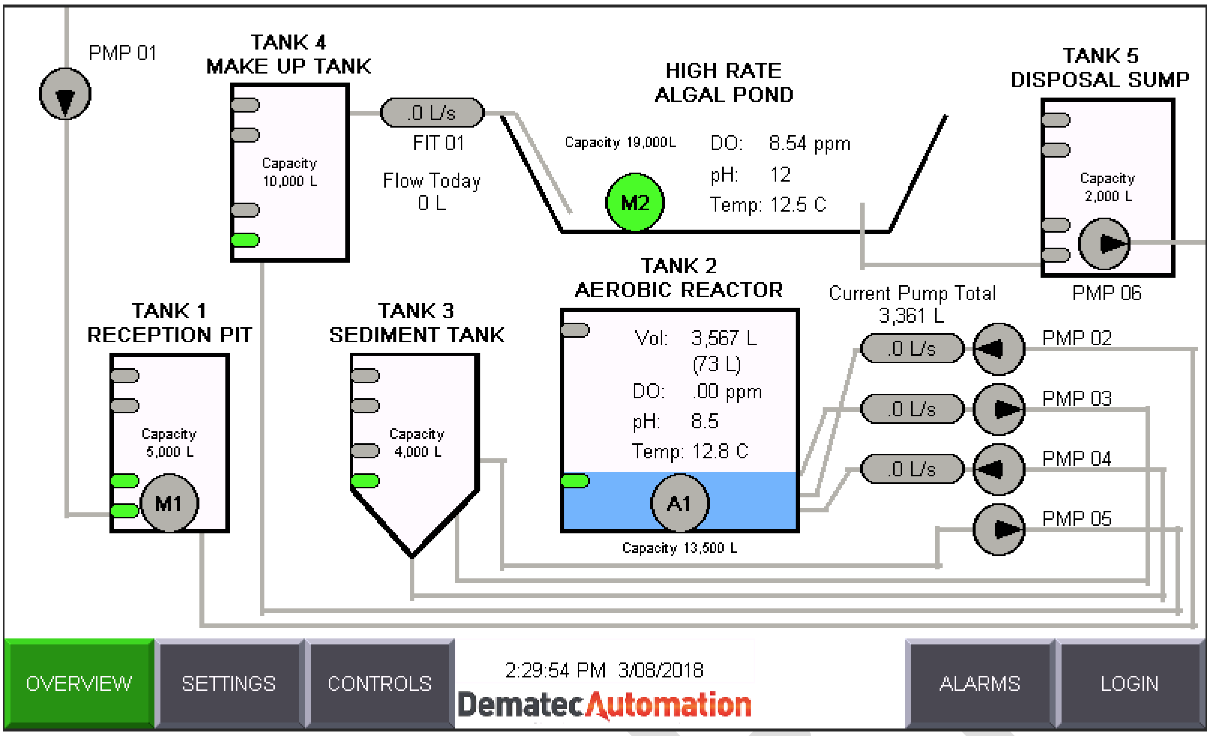

Figure 2.2 Roseworthy integrated system overview

To establish ideal operating parameters, pig slurry based trials were conducted in the 13500 L capacity aerobic reactor; the impact of air saturation and theoretical hydraulic retention time (THRT) on suspended solid (SS) removal and nitrification of ammonium (NH_4-N) in the anaerobically pre-treated pig slurry (ANPS) are the focus of this experimental set up. Secondly, the aerated pig slurry with a reduced ammonium level will then be used for an algal growth experiment.

To enable successful algal biomass production in the HRAP the performance of the aerobic reactor required optimization with regards to nitrification and suspended solids reduction.

The integrated aims of the current study were:

- *To optimize aerobic reactor performance with regards nitrification and suspended solids reduction to enable*
- *Determination of the growth potential of microalgae in piggery slurry following consecutive anaerobic-aerobic pre-treatment.*

2.2 Collection of anaerobically pre-treated pig slurry (ANPS) at anaerobic lagoon

At Roseworthy piggery, the anaerobic lagoon desludging process is usually undertaken twice a year (i.e. once in summer (Plate 2.3) and once before/in winter).

Plate 2.3 Roseworthy Piggery anaerobic pond following desludging.

Plate 2.4 Installation of float and foot valve for extraction of anaerobically treated slurry.

Plate 2.5 & 2.6 Floating inlet installed on the anaerobic lagoon.

A 50mm diameter 0.5m length foot value was installed on two floating blocks attached to the influent pipe (Plate 2.4) for ANPS delivery to pig slurry reception tank (T1). The floating influent suction point was strategically positioned in the middle of the lagoon, allowing at least 0.5m clearance from both top and bottom of the lagoon so uptake of floating debris or sludge was minimal (Plate 2.5 & 2.6).The installation of the foot valve also resolved the problem of maintaining the influent pump primed.

2.3 Operation of the aerobic reactor

2.3.1 Aeration regime (DO 3-4 mg O_2 L^{-1}, approximately 36 to 48% aeration at 25⁰C)

Aeration level is an important factor to consider when designing the treatment process as it provides the oxygen input needed for the oxidation of NH_4^+-N to NO_3-N. These aeration levels needed to be both economical and suitable for nitrification while optimising the DO requirement. Based on previously laboratory experiments conducted (Hawley, 2019), the most cost-effective aeration regime was determined at a DO saturation of 36.31% and 48.41% at 25⁰C within DO of 3 - 4 mg O_2 L^{-1}. The aerator (Acqua & Co Force 7.1, 1.1 kW) in the aerobic reactor, was installed pointing upward at 35 degrees with an oxygen delivery rate of 3.35 m^3 O_2 h^{-1}. Aeration was controlled using an ABB DO transmitter controller (4640/5000) at set points 3 and 4 mg O_2 L^{-1}.

2.3.2 Residence time (theoretical hydraulic retention time, THRT)

NH_4^+ oxidising bacteria are slow growing organisms, that require a treatment time of 2.5-14d (Evans *et al.*, 1979). Outside of this range would not be considered economically viable (Evans *et al.*, 1979, Evans *et al.*, 1986). Prior to the commencement of the trials, the ANPS in the reactor was inoculated (10% v/v) with nitrifying activated sludge inoculum (NASI). The reactor population was maintained by aerating the 10,000L ANPS at 3 -4 mg O_2 L^{-1} for 9 days in an attempt to acclimatise the nitrifiers to the high levels of NH_4^+-N found in the ANPS.

To encourage nitrification and avoid nitrifier washout, a THRT of 5 d was selected, later extended to 10 d. A slurry influent flow rate of 2000L and 1000L was used to achieve a 5 d and 10 d THRT, respectively whilst maintaining a 10,000 L working volume in the aerobic reactor.

2.3.3 Experimental configuration of the aerobic reactor (AR)

Time permitted evaluation of three configurations of aerobic reactor operation which are shown in Table 2.1.

Table 2.1 Summary of experimental configuration of the aerobic reactor (AR) for different THRT trials at DO 3-4 mg, i.e. 36.31%-48.41% DO saturation at 25 °C.

Trial no.	THRT (d)	Experiment duration (d)	Aeration set-point (DO mg O_2 L^{-1})	Aeration (% saturation)	Initial pH	Conductivity (µS/cm)
AR-5d	5	5	3-4	36 - 48	7.6	10260
AR-10d	10	10			7.6	10250
AR-28d	10	28			7.6	10250

2.4 Microalgae inocula and residence time in HRAP

2.4.1 Trial setup for HRAP (19,000 L capacity at 0.3m operational depth)

The primary objective was to determine of the growth potential of microalgae in piggery slurry following consecutive anaerobic-aerobic pre-treatment, by using the available aerated ANPS from the aerobic reactor. Three experiments were conducted:

1. **HRAP development of an algal population: 1000L (5% v/v) of aerated ANPS from 10d THRT-10d, cultivated with tap water (10d)**
    - Aim: To develop a microalgal population in HRAP by using aerated ANPS nutrients
    - Ratio to volume: 1000L aerated ANPS, 18,000L tap water (i.e. ~5% v/v)
    - Algal inocula: 60L (i.e. 0.3% (v/v) of total volume to HRAP, 19,000L)
    - Duration: 10 days
    - Start chlorophyll *a*: 0 g L^{-1}
2. **HRAP Trial 1: Algal growth over 20 d in (10 % v/v) of aerated ANPS treated at a 10d THRT.**
    - Aim: To investigate the introduction of a higher % of aerated ANPS, equivalent to the dosage of 1 day out of a 10d THRT in HRAP, single batch
    - Ratio to volume: 2000L aerated ANPS, 17,000L existing algal developed HRAP wastewater (i.e. ~10% v/v)
    - Algal inocula: no additional inocula
    - Duration: 20 days
    - Start chlorophyll *a*: 1.333 g L^{-1}
3. **HRAP trial 2: Algal growth over 7 d in (50 % v/v) of aerated ANPS treated at a 10d THRT**
    - Aim: To investigate the cultivation and survivability of algae in a lower conductivity concentration (~ approximately 2900 µS cm^{-1})
    - Ratio to volume: 9,500L tap water, 9,500L existing algal developed HRAP wastewater cultivated by aerated ANPS (i.e. ~50% v/v)
    - Algal inocula: no additional inocula
    - Duration: 7 days
    - Start chlorophyll *a*: 0.490 g L^{-1}

2.5 Sampling

Sampling of the aerobic reactor was carried out for 30 days and effluent samples from the aerobic reactor were collected twice daily, at 6 am and 6 pm, by a refrigerated (1°C) autosampler, (Avalanche® Sampler, Teledyne ISCO Lincoln, NE). The two samples collected each day formed a daily composite sample (0.4 L). The results for these samples were considered an average over the day. After the samples had been retrieved, they were transported, while being refrigerated at 1°C in the dark, and analysed within 24 h.

2.6 Wastewater quality analysis

On-site analysis of wastewater collected from the automatic samplers

A Flinders University minor equipment application resulted in the purchase of a Yellow Springs Instruments Pro Digital Multiprobe Sensor (YSI Ltd Ohio), incorporating measurement of temperature, dissolved oxygen, specific conductivity, pH, ammonia-nitrogen (NH_4^+-N), and nitrate-nitrogen (NO_3^-N). This increased efficiency of analysis given the limited time available for this project and enabled on-site measurement. The intermediate product of nitrification, NO_2-N, however, could not be measured by this probe.

Measurements from the YSI sonde are recorded every 10 seconds from which a mean value is calculated over the period required to gain a stable reading (5min, sometimes longer). This method of data collection does not enable estimate of the error associated with the mean e.g. a standard deviation.

Laboratory analysis

Water quality analyses were carried out by using American Public Health Association Standard Methods (APHA, 1992) and are detailed in Fallowfield and Cheng (2018).

Total Suspended solids (TSS)

Triplicate, 40 mL aliquots of the respective wastewater samples were filtered through 90 mm diameter, dried (105°C; 18-24 h), glass microfiber filters (GFC; LabServ, LBSOGF 090, Australia). The filters were dried overnight (105°C; 18-24 h) and reweighed. The mean TSS (g L^{-1}) was determined from triplicate determinations according to Equation 2.1 (APHA, 1992).

$$\frac{(W\ final)-(W\ initial)}{V\ smple\ (L)} = SS\ g/L \qquad \textbf{Equation 2.1}$$

Where,
Wfinal = final weight (g) of filter paper and slurry residue
Winitial = Initial weight (g) of filter paper
Vsample = Volume of filtered samples (L)

Total Carbon (TC), inorganic carbon (IC) and total organic carbon (TOC) analysis

Wastewater samples were diluted 100 times with Milli-Q® water.TC, TOC and IC were measured (g C L^{-1}) using a Shimadzu TOC-LCSH/CSN 500 analyser (Shimadzu Corporation, Japan). A carbon mass balance was performed to track the input, conversion, and accumulation of carbon during nitrification using Equation 2.2.

$$\boldsymbol{TC_{massbalance} = C_{TC} - C_{TOC} - C_{IC}} \qquad \textbf{Equation 2.2}$$

Where,
CTC= Concentration (g L^{-1}) of TC in sample
CTOC = Concentration (g L^{-1}) of TOC-C in sample
CIC = Concentration (g L^{-1}) of IC-C in sample

2.7 Enumeration of E.coli

To quantify *E. coli* the Colilert Quanti-Tray® method (IDEXX Laboratories, USA) was used. The values were reported as Most Probable Number (MPN) per 100 mL.

3 RESULTS

3.1 Aerobic reactor performance

Three experimental runs were conducted,

- AR-5d – 5d THRT over 5d
- AR-10d – 10d THRT over 10d
- AR-28d – 10d THRT over 28d

The DO concentration in the aerobic reactor mixed liquor was maintained between 3-4mg DO L^{-1} using the DO transmitter controller to activate and deactivate the aerator below or above these set point values.

3.2 pH

Including the preparation of inoculum and optimising the system operation, the period of experimentation took place between January and late April in 2019. Over the whole period of reactor operation the mean pH in the mixed liquor ranged from pH 8.56 to 7.00 (Figure 3.1). This was consistent with the pH range expected for nitrification; 7.2-9.0 and fluctuated with the degree of nitrification.

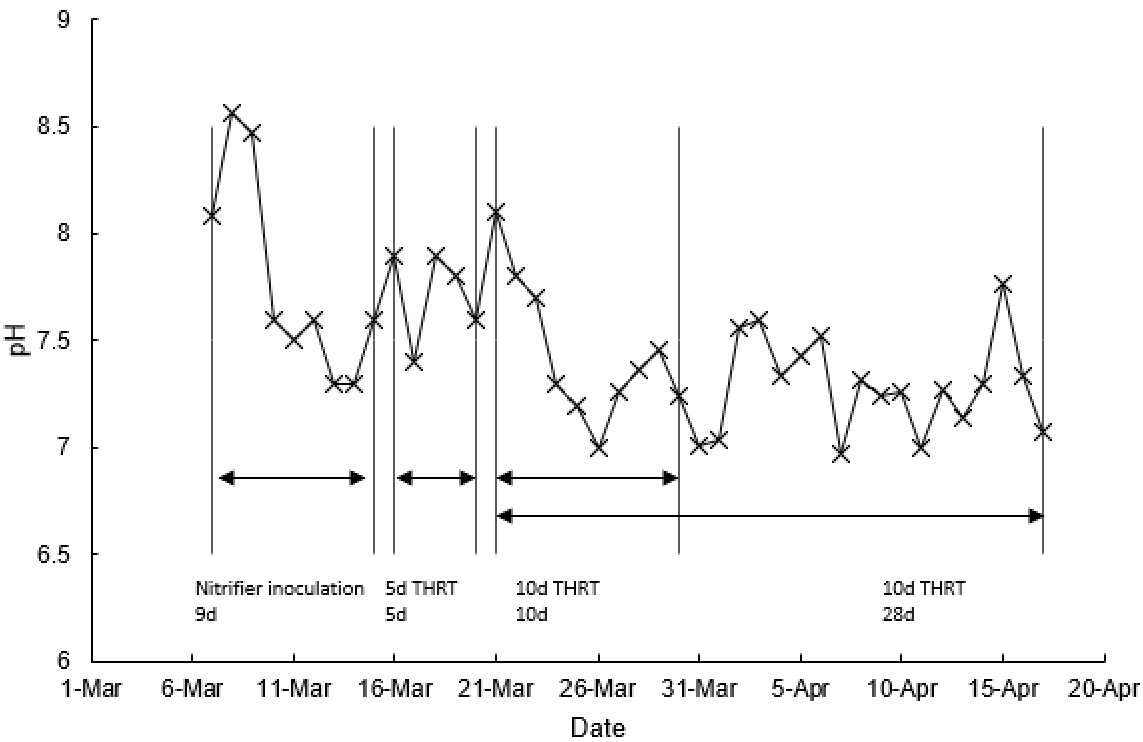

Figure 3.1 The pH of the mixed liquor in the aerobic reactor over the period of operation. 6-15 March (9days) was used for pre-experiment nitrifiers acclimatisation; 5d THRT was conducted on between 16-20 March (5 days); 10d THRT was conducted on between 21 March – 17 April (21-30 March (10 days), 21 March-17 (April 28 days))

3.3 DO aeration frequency at 3-4 mg O_2 L^{-1} (36.31%-48.41% at 25 °C)

The pilot plant was operated and monitored remotely using cloud-based software. There is a connection to a secure Dematec Automation IIOT (Industrial Internet of Things) database, which provides a cloud-based location for data collection, storage, backup, and trending. DO and temperature trends were recorded every 30 seconds but due to the large quantity of data, only 1751 points are shown in Figure 3.2 over the period from 6 March to 17 April 2019 with an average 40 event points per day on each DO and temperature. Frequent cleaning on DO probe was required to minimise the sudden, errant, decreases in DO concentrations observed in the continuous data logging in Figure 3.2. Notwithstanding, DO concentration was effectively maintained, when the reactor was operated at a THRT of 10d, within the desired range at an average of 3.35 mg O_2 L^{-1}, equivalent to 38.34%-51.12% DO saturation at a mean temperature of 27.95°C. The DO set range was not maintained when the reactor was operated at a THRT of 5d (15^{th} - 20^{th} March; Fig. 3.2).

Although DO aeration is set at 3-4 mg O_2 L^{-1}, it varied over the period of experiment due to the concentration of NH_4-N presented in ANPS. At steady state (28d) at a mean DO concentration of 3.35 mg O_2 L^{-1} (10d THRT, 10,000L) the total time of aerator operation was 2.3h d^{-1}.

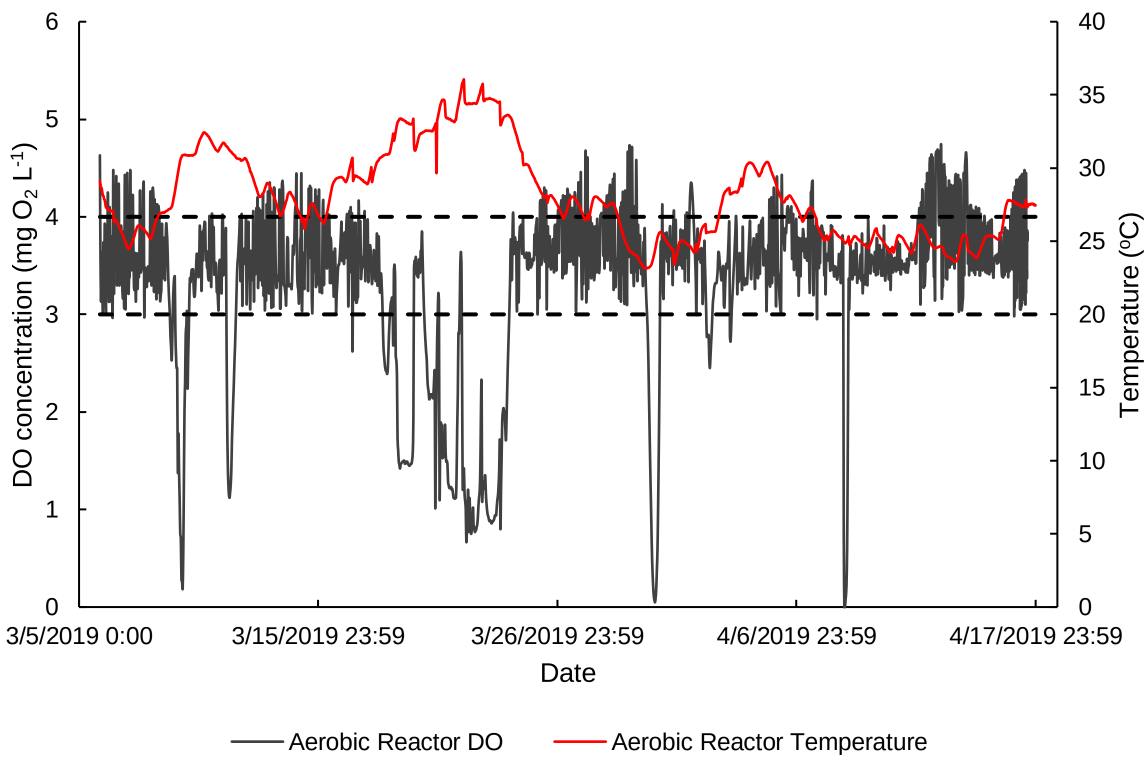

Figure 3.2 The temperature and dissolved oxygen concentration (mg O_2 L^{-1}) of the mixed liquor in the aerobic reactor over the period of operation.

3.4 Effect of theoretical hydraulic retention time on suspended solids removal

Results of TSS removal over time were obtained for each operational configuration analysed, (Figure 3.3). Inlet TSS concentrations varied, however, they were consistently between 1.35 and 1.38 g L^{-1} in the ANPS used for each experimental THRT. Figure 3.3 showed that under aerobic conditions over 33%, 36% and 51% of TSS were removed post treatment when the AR was operated at 5d THRT-5d, 10d THRT-10d and 10d THRT-28d respectively.

An increase in THRT from 5d to 10d yielded a slight improvement in TSS removal, with 33% and 36% removed a 5d or 10d period, respectively. 0.91 g L^{-1} and 0.89 g L^{-1} of total suspended solids were detected at the end of the aeration period (1 cycle), and therefore no statistical difference observed in the mean outlet TSS content between these two trials ($p \geq 0.05$). Interestingly, the amount of TSS removed was found to 0.32 g L^{-1} greater after three THRT cycles which was a statistically significant decline in outlet concentrations post treatment ($p \leq 0.05$) at the longer THRT and at the same DO saturation when compared between 10d THRT-10d and 10d THRT -28d.

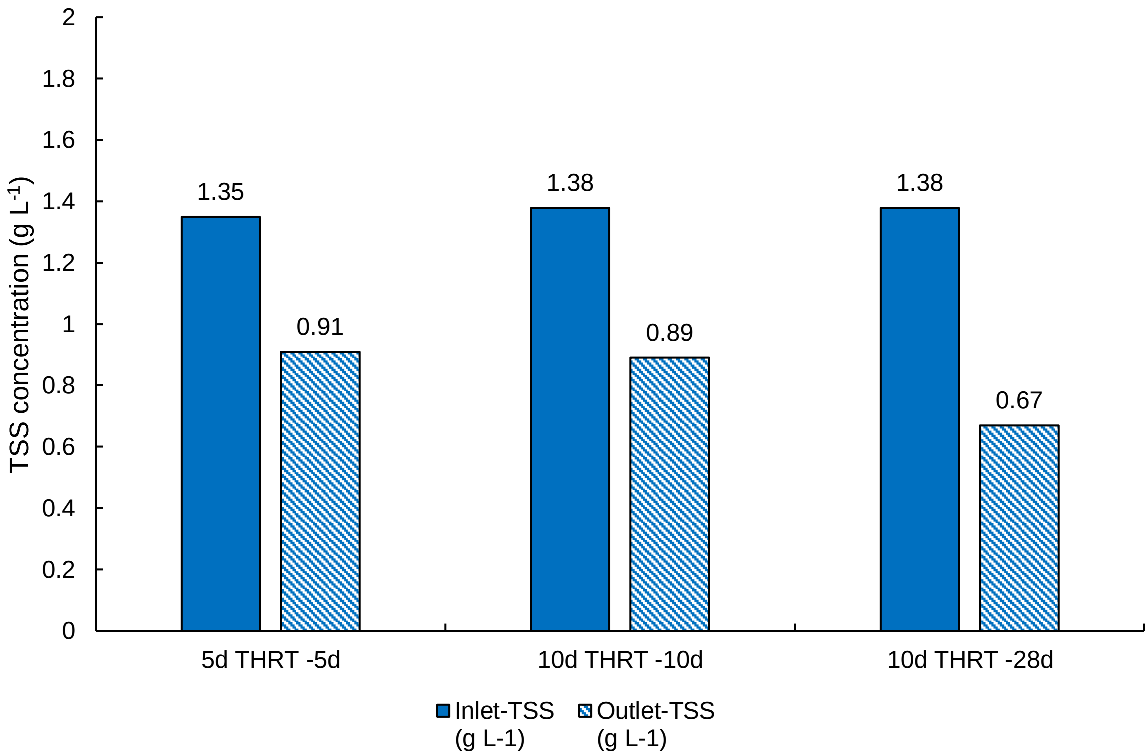

Figure 3.3 Comparison of the effect of theoretical hydraulic retention time on total suspended solid concentration following the aerobic treatment (3-4 mg O_2 L^{-1}) of anaerobically pretreated pig slurry.

3.5 Effect of residence time (THRT 5d vs 10d) on ammonia oxidation and nitrification

Summarised in Figures 3.4–3.5 are the results of ammonia oxidation and nitrification by comparing the quantifiable N (NH_4^+-N and NO_3^--N) content of both the inlet and treated outlet in order to evaluate the inter-conversion of inorganic-N fractions following subsequent treatment in the aerated ANPS at different residence times.

In Figure 3.4, an increase in THRT to 10 d demonstrated a significant improvement in nitrification levels post treatment when compared to 5d THRT. A reduction in NH_4^+-N of up to 51.7% from 1.47 in the inlet to 0.71 g L^{-1} in the outlet was obtained; the highest oxidation rate achieved across the three trials. The extended cycle in 10d THRT up to 28 days did not achieve a higher reduction in NH_4^+-N. While in 5d THRT, a relatively lower reduction in NH_4^+-N of up to 32.3% from 1.55 in the inlet to 1.05 g L^{-1} in the outlet was obtained

A comparison of mean outlet nitrogen concentrations at both THRTs found nitrification to be at its greatest at the longer THRT 10 d after approximately 3 residence times (Figure 3.5). This was denoted by a significant increase in NO_3^--N accumulation. NO_3^--N levels were 0.04 g L^{-1} higher at 10 d than at 5 d for each individual trial, while no difference in NO_3^--N concentration was found at the 5d THRT post-treatment. This could possibly due to insufficient treatment residence time and nitrifier washout which will be examined in the next section. A significant increase in NO_3^--N concentrations was detected in 10d THRT after approximately 3 residence times, correspondingly reaching 0.52 g L^{-1} NO_3^--N with two-fold (205.9%) increased from 0.17 g L^{-1} NO_3^--N inlet. With only 1 residence time in 10d THRT, the increase was marginal from 0.17 g L^{-1} to 0.21 g L^{-1} NO_3^--N with 23.5% increased concentration.

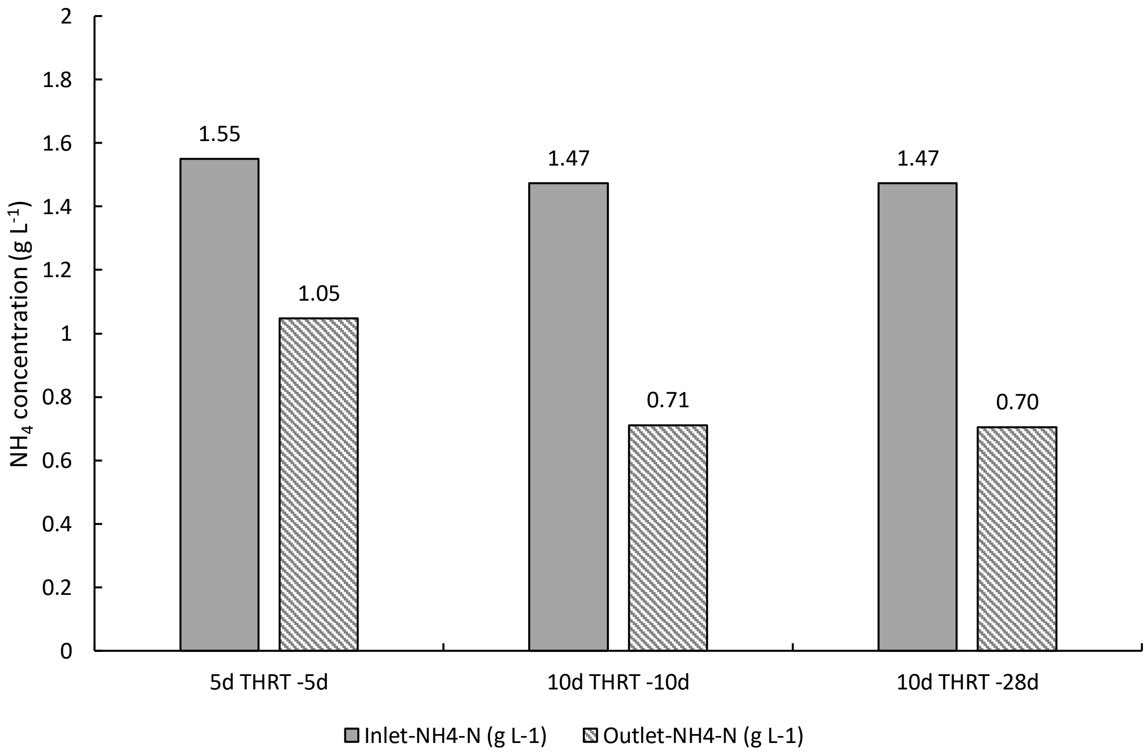

Figure 3.4 Comparison of the effect of theoretical hydraulic retention time (THRT) on ammonia removal following the aerobic treatment (3-4 mg O_2 L^{-1}) of anaerobically pretreated pig slurry.

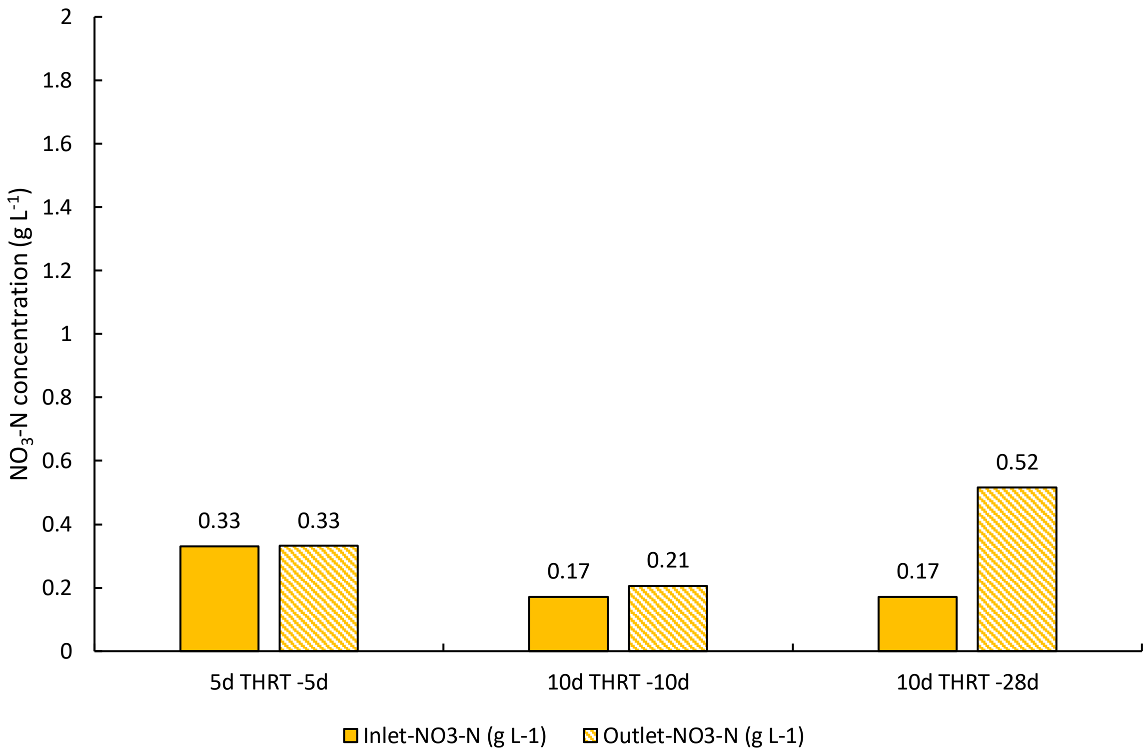

Figure 3.5 Comparison of the effect of theoretical hydraulic retention time (THRT) on nitrate concentration following the aerobic treatment (3-4 mg O_2 L^{-1}) of anaerobically pretreated pig slurry.

Figure 3.6 shows a slight increase of NO_3^--N at the beginning of trial but no nitrification was detected after 1 residence time when the reactor was operated at 5d THRT. This is most likely due to insufficient duration of treatment at the imposed 5d THRT and potentially nitrifier washout, with a confirmation of slight increase of NH_4^+-N from 0.84 to 1.05 g L^{-1} NH_4.

The 10d THRT trial on the other hand did not show any indication of nitrifying bacteria wash-out. The mean NO_3^--N concentration was maintained between 0.5-0.6 g L^{-1} NO_3 over the 28d which represented almost 3 cycles of the 10d THRT (Figure 3.7)

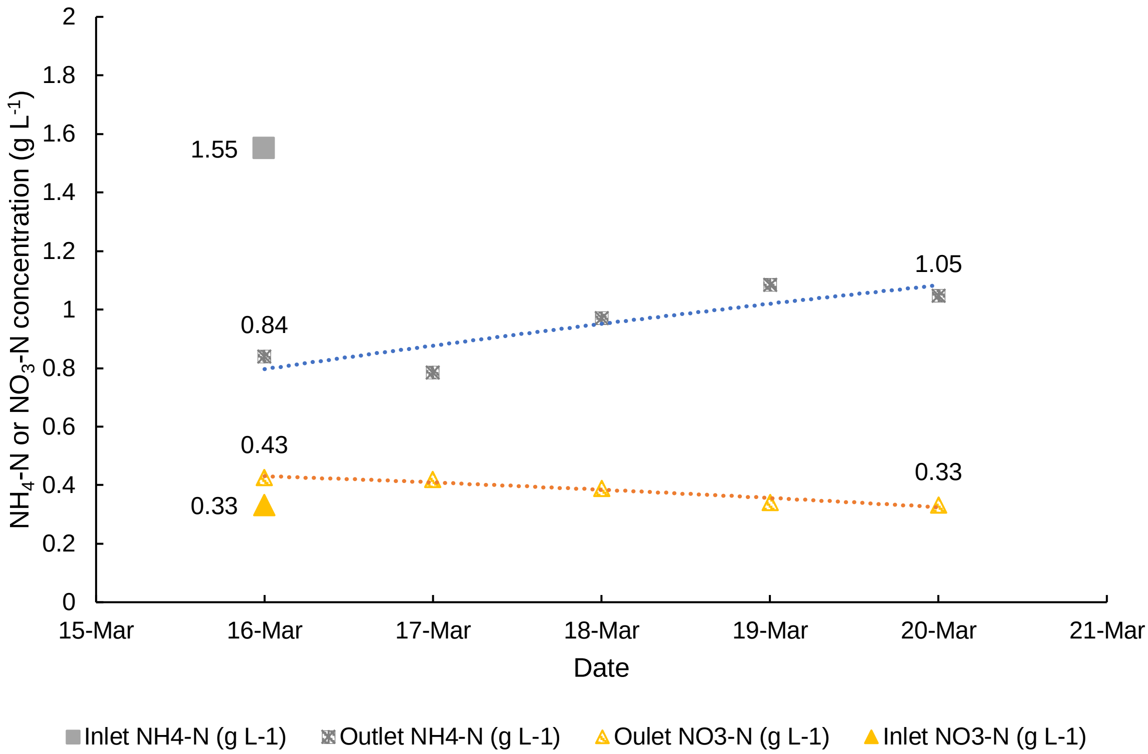

Figure 3.6 The inlet and outlet concentration of NH4-N, NO_3-N following aerobic treatment (3-4 mg O_2 L^{-1}) at a 5d theoretical hydraulic retention time (THRT).

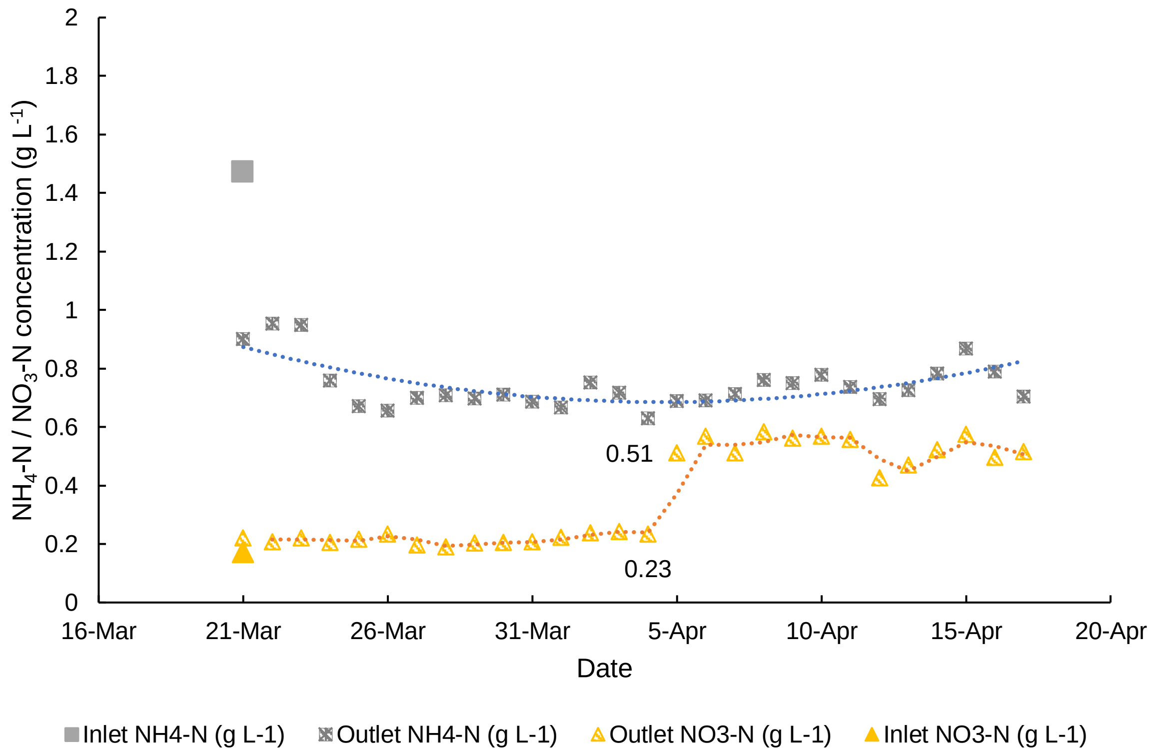

Figure 3.7 The inlet and outlet concentration of NH_4-N, NO_3-N following aerobic treatment (3-4 mg O_2 L^{-1}) at a 10 d theoretical hydraulic retention time (THRT) over a period of 28d (3 THRT cycles)

3.6 Comparison of inlet and outlet nitrogen mass balances following treatment at different theoretical hydraulic retention times (THRT)

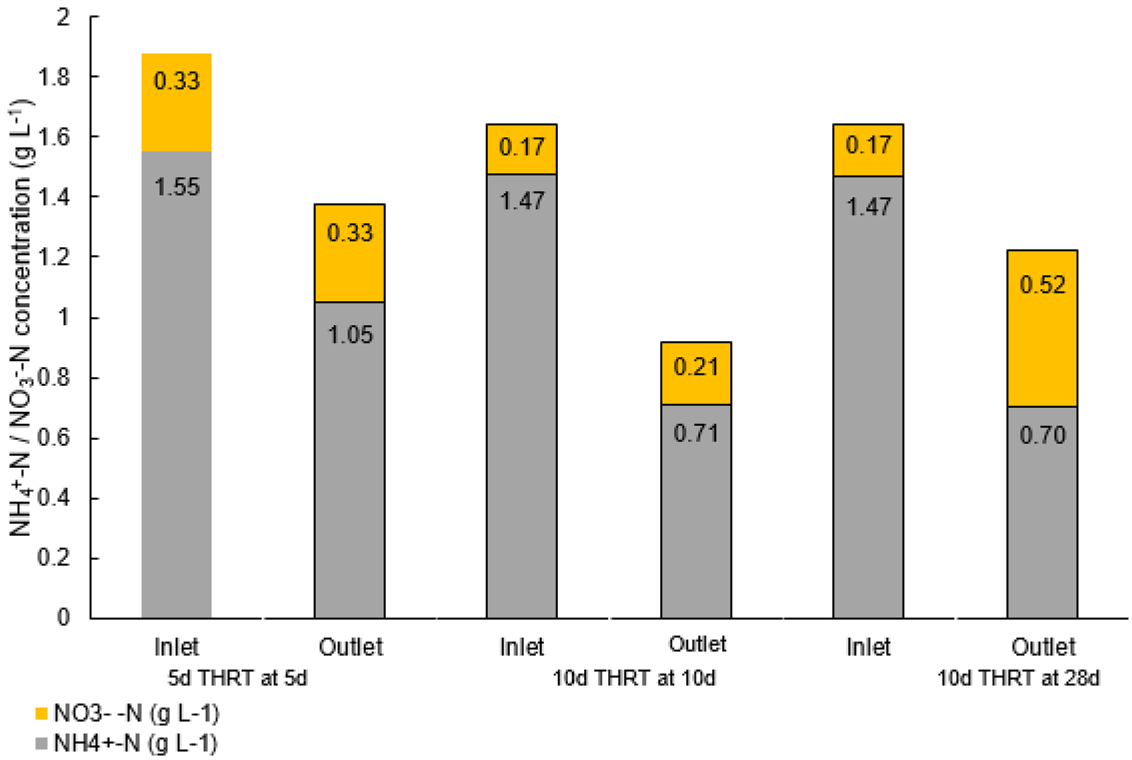

Figure 3.8 Inorganic nitrogen speciation in inlet and outlet slurry following aerobic treatment (3-4 mg O_2 L^{-1}) theoretical hydraulic retention times (THRT) of 5 and 10d.

Figure 3.8 shows the nitrogen speciation of the ANPS inlet and the outlet following aerobic treatment and THRT of 5 and 10d. Not all the inorganic nitrogen present in the inlet can be accounted for in the treated outlets. The cause may be threefold, NO_2-N and intermediate inorganic nitrogen species in the pathway to NO_3-N production was not measured, inaccuracy in the measurement of both NH_4-N and NO_3-N or loss of ammonia due to volatilisation during aeration. Only 15% of the inlet nitrogen was unaccounted in the 5d THRT treatment, however, treatment at 10d THRT showed the unaccounted nitrogen decreasing from 44% to 26% as the retention time cycle was increased to 28d. Data from the aerobic reactor operated at a 10d THRT for 28d is likely representative of the steady state condition. The apparent loss of nitrogen in this condition is most likely a consequence of not determining NO_2-N concentrations.

Although the TSS remained relatively high after 1 residence time, a notable colour change from dark taupe (greyish brown) to a more orange-brown hue, and most of its offensive odour had completely disappeared by just 5d THRT after 5 days.

3.6.1 Comparison of aerobic reactor & ambient air temperature

A Bureau of Meteorology weather station (34.51° S 138.68° E, station 023122) is located approximately 250 metres from the aerobic reactor. A mean ambient air temperature and mean daily global solar exposure were recorded of 19.67°C (Figure 3.9) between 6 March and 17 April, 2019. The mean temperature of the mixed liquor was 27.95°C in the aerobic reactor operating at DO 3-4 mg O_2 L^{-1} (36.31%-48.41% DO saturation at 25 °C). The higher temperature (8.28°C) of the mixed liquor is a result of both heat recovered from the 1.1kW aerator, metabolic heat derived from microbial carbon oxidation and radiant energy adsorbed by the black coloured tank.

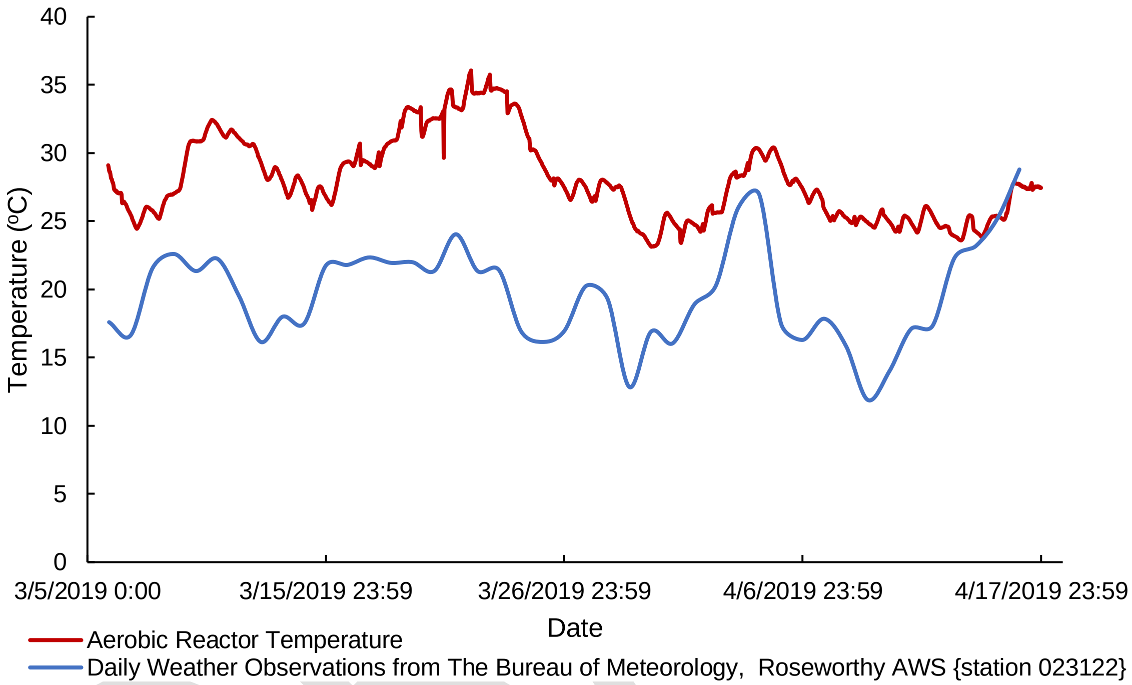

Figure 3.9 Ambient air temperature recorded at Roseworthy AWS (Station 023122) and in the mixed liquor of aerobically treated (3-4 mg O_2 L^{-1}).

3.6.2 Daily global solar exposure

The daily global solar exposure recorded between 6 March and 17 April, 2019 at the BoM weather station (34.51° S 138.68° E, station 023122) is shown in Figure 3.10. The mean irradiance was 4.52 kW h m^{-2}.

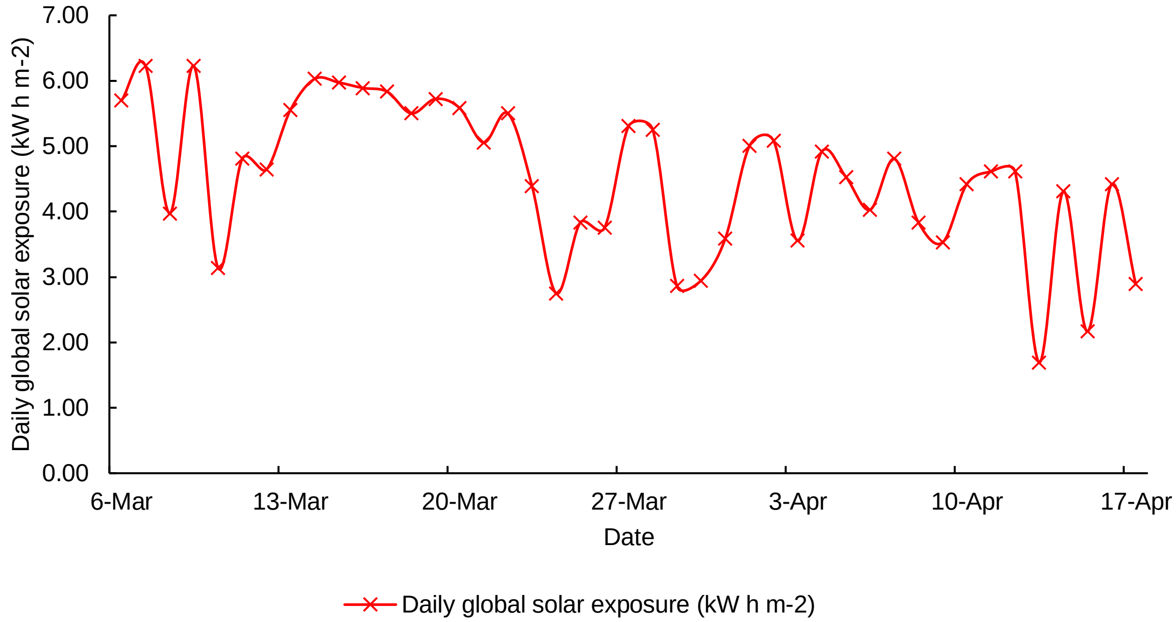

Figure 3.10 The daily global solar exposure recorded at Roseworthy AWS (Station 023122) during the experiment period. It is measured from midnight to midnight.

3.7 Reduction in carbon levels (total carbon, total organic carbon, inorganic carbon)

Concentrations of inorganic and organic carbon recorded over the 5 (5d THRT) and 10d THRT operated for 10,28d aeration periods are shown in Figures 3.11 & 3.12.

Mean inlet TC concentrations ranged from 1.31 (5d THRT) to 1.15 g L^{-1} (10d THRT). The TOC and IC content equated to the sum of TC. The addition of aerobic treatment stimulated reduction yields up to 54%, 60%, and 65%; with final outlet TC concentrations at 0.60 (5d THRT, 5d), 0.46 (10d THRT, 10d), and 0.40 g L^{-1} (10d THRT, 28d), respectively. The reduction yields, providing evidence of carbon oxidation during aerobic treatment, were 15%, 31%, and 24%. The final outlet TC concentrations were 0.41 (5d THRT, 5d), 0.29 (10d THRT, 10d), and 0.33 g L^{-1} (10d THRT, 28d).

Of particular interest was the significant gradual reduction in IC. Mean IC concentrations were consistently lower in the treated outlet than in the inlet for all operating parameters tested (Figure 3.12). 10d THRT at 28d was notable in this regard with an outlet IC concentration 89% lower post treatment; from 0.72 to 0.08 g L^{-1}. Over the trials between 5d and 10d THRT at 1 residence time, IC concentrations were observed to have reduced significantly by 77% and 78% respectively, from 0.83 to 0.19 g L^{-1} at 5d THRT and from 0.72 to 0.16 g L^{-1} at 10d THRT. This is likely due to the consumption of inorganic carbon (CO_2 and $CaCO_3$) as an energy source during nitrification. However, an increase in THRT residence cycle was shown to have less significant effect on reduction in carbon levels when compared to the ammonia oxidation and nitrification.

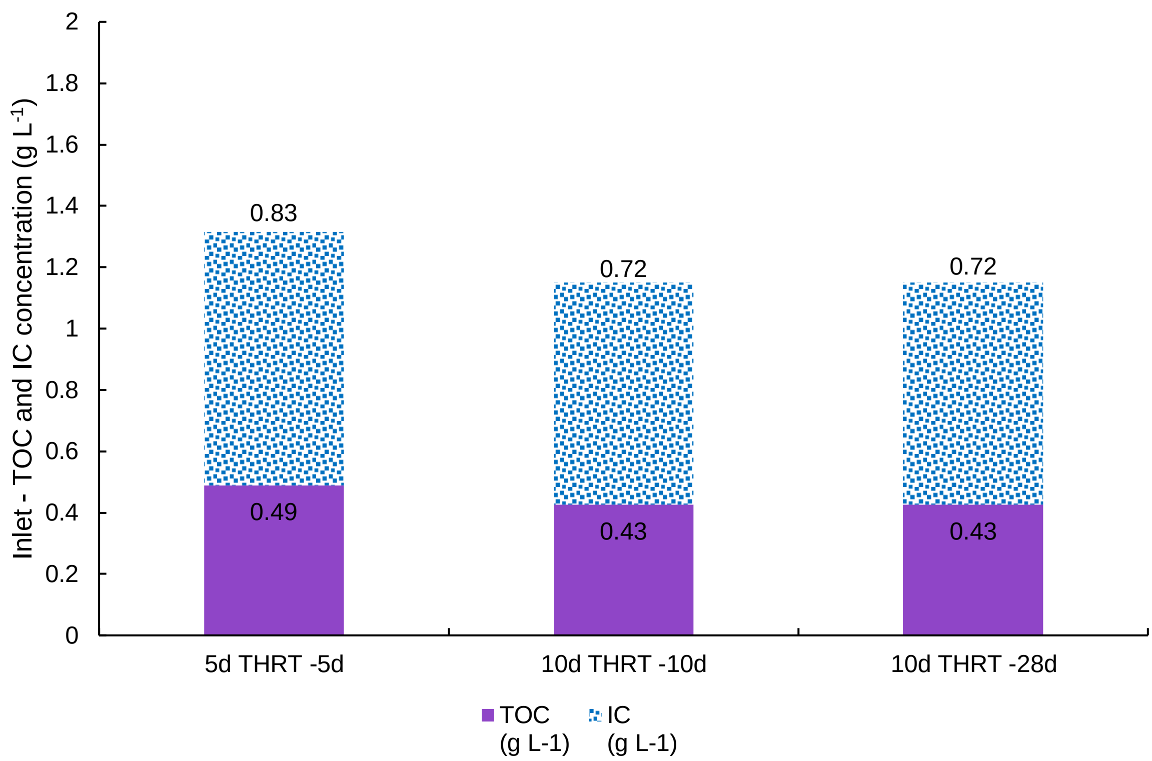

Figure 3.11 Comparison of the total organic carbon (TOC), inorganic carbon (IC) concentration of the aerobically pretreated slurry used in the resective the aerobic treatment (3-4 mg O_2 L^{-1}) experiments.

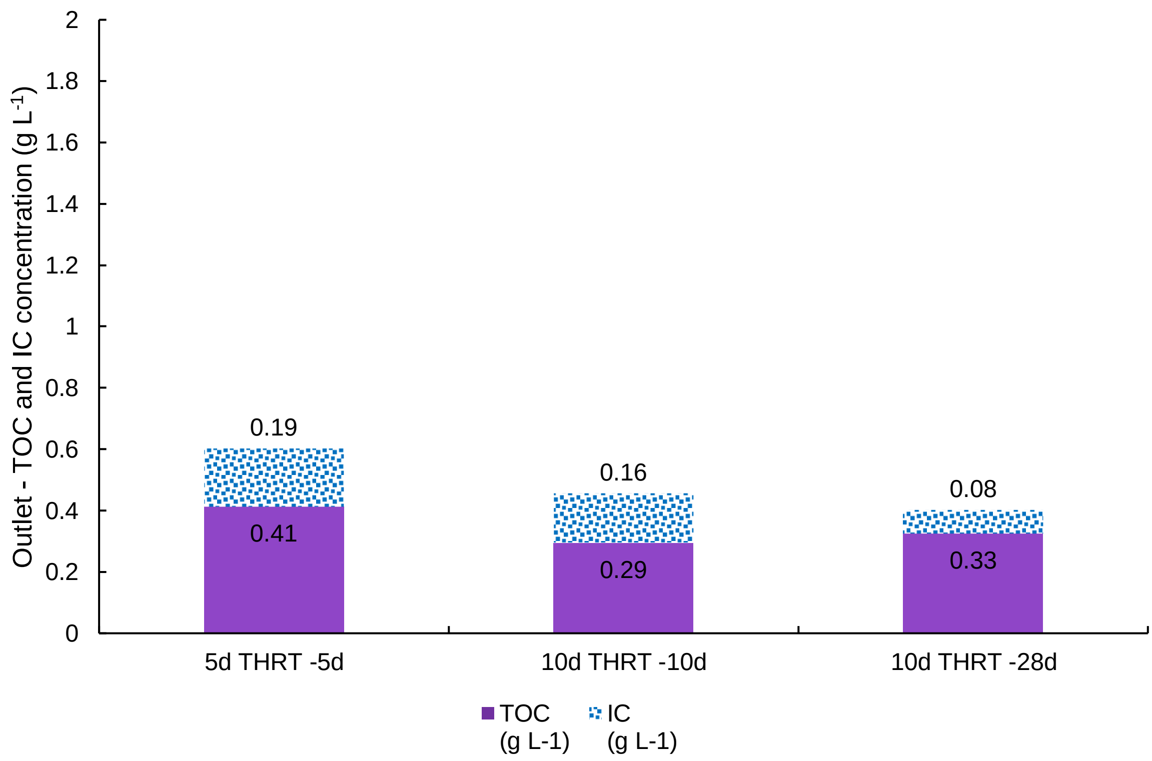

Figure 3.12 Comparison of the effect of theoretical hydraulic retention time (THRT) on total organic carbon (TOC) and inorganic carbon (IC) concentration following the aerobic treatment (3-4 mg O_2 L^{-1}) of anaerobically pretreated pig slurry.

3.8 Daily energy consumption estimates for aeration (1.1kw aerator)

The estimate of daily power consumption from the areator is affected by a serveal factors including initial and current NH_4^+-N concentrations, operational volume, temperature, and DO saturation regimes. At DO 3-4 mg O_2 L^{-1} with a working volume of 10,000L, the operation of aerator varied over the period of expierment due to the concentration of NH_4^+-N presented in the ANPS. Based on the mean set point concentration of 3.35 mg O_2 L^{-1} DO at a 10d THRT, the total time of aerator operation was determined 2.3h at steady state.

The daily power consumption of the 1.1kw aerator was estimated, when the reactor was at quasi-steady state after 28d operation at a DO setpoint of 3-4 mg O_2 L^{-1} and a THRT of 10d, to be 2.53 kW d^{-1}.

3.9 Growth of algae in the HRAP

3.9.1 Composition of aerated ANPS feedstock (stored in makeup tank T5) for algal cultivation in the HRAP

The aerobically treated feedstock was stored in the makeup tank T5 (Figure 2.1) at the end of each aerobic treatment trial. A profile of each feedstock is summarised in Table 3.1. Due to the time constraints, the aerated ANPS obtained from treatment at a 10d THRT after 1 retention time was used as a growth medium in the HRAP (highlighted in Table 3.1)

Table 3.1 Summary of aerated ANPS obtained from different THRTs after aerobic trials at DO 3-4 mg, i.e. 36.31%-48.41% DO saturation at 25 °C (stored in make-up tank T5)

	NH_4 -N ($g\ L^{-1}$)	NO_3-N ($g\ L^{-1}$)	pH	Conductivity ($\mu S\ cm^{-1}$)	TOC ($g\ L^{-1}$)	TC ($g\ L^{-1}$)	IC ($g\ L^{-1}$)	TSS (g/L)
5d THRT -5d	0.90	0.22	8.1	10544	0.42	0.57	0.16	0.85
10d THRT -10d	0.67	0.45	7.6	10260	0.28	0.53	0.25	0.85
10d THRT -28d	0.64	0.61	7.69	9686	0.36	0.41	0.05	0.73

3.9.2 HRAP development of an algal population: Algal growth over 10 d in (5% v/v) of aerated ANPS treated at a 10d THRT.

The HRAP was inoculated with 60L of wastewater containing a mixed algal population from the HRAP treating wastewater from the community of Kingston on Murray.

Chlorophyll *a (Chl a) and total suspended solids (TSS)*

Initial colour of the mixed liquor in the HRAP was brownish-orange (Plate 3.1). Table 3.2 shows that over time a Chl *a* concentration and the TSS, representative of algal solids, increased significantly over the10d cultivation period to 1.59 mg Chl *a* L^{-1} and 1.27 g TSS L^{-1} respectively.

Table 3.1 also shows that initial concentrations of nutrients increased int the batch culture increased over time due to evaporative water loss. Consequently, a tap timer was installed to deliver tap water to compensate for daily evaporative loss and maintain pond depth and volume in subsequent batch culture experiments.

Table 3.2 Algal growth in (5 % v/v) treated aerobic reactor effluent: Wastewater composition.

	NH_4 -N ($g\ L^{-1}$)	**NO_3-N ($g\ L^{-1}$)**	**pH**	**Cond ($\mu S\ cm^{-1}$)**	**TOC ($g\ L^{-1}$)**	**TC ($g\ L^{-1}$)**	**IC ($g\ L^{-1}$)**	**TSS (g L-1)**	**Chl *a* ($mg\ L^{-1}$)**
Initial composition	0.03	0.02	7.4	513	0.01	0.03	0.01	0.04	UD
After 10d cultivation	0.09	0.07	8.6	NA	0.62	0.75	0.13	1.27	1.59

* Equivalent to 5% (v/v) obtained from aerated ANPS in makeup tank (T5) from 1 residence time of 10d THRT
UD: undetected; Cond: conductivity

Plate 3.1 A significant colour change on a developed microalgal population by using nutrients from aerated ANPS, from a brownish-orange (left) to green (right)

3.9.3 HRAP Trial 1: Algal growth over 20 d in (10 % v/v) of aerated ANPS treated at a 10d THRT.

Algal growth

Chlorophyll a and total suspended solids

Figure 3.13 shows over time a gradual decrease in both TSS and Chl *a* concentrations during the 20 d cultivation period from 1.21 to 0.88 g TSS L^{-1} and 1.33 to 0.95 mg Chl *a* L^{-1} respectively.

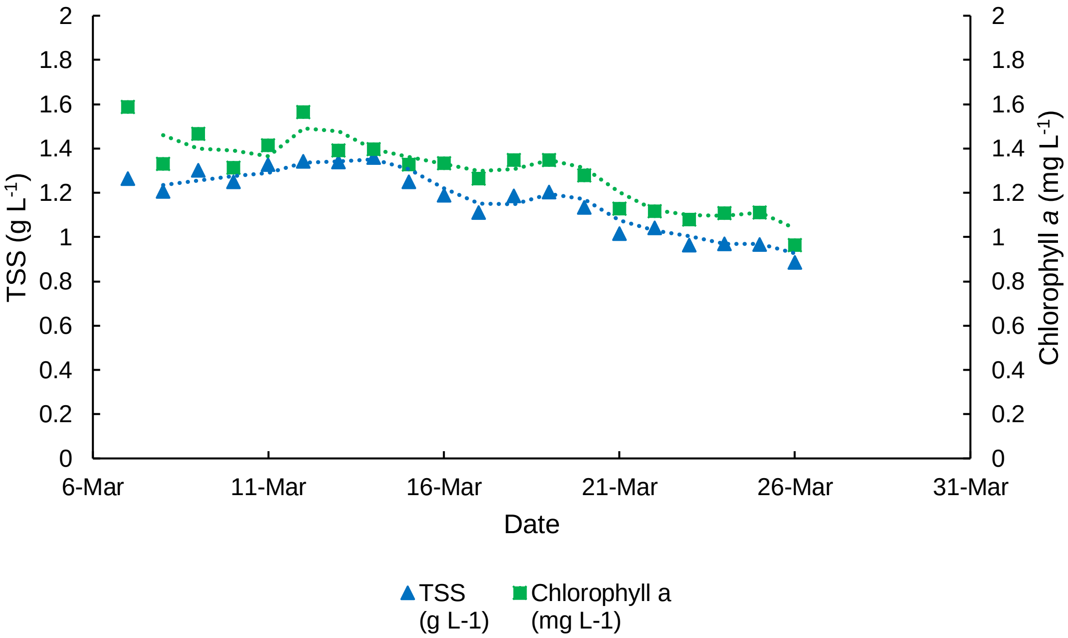

Figure 3.13 Algae grown in 10% aerobic reactor effluent: Chlorophyll *a* and total suspended solids concentration.

A correlation between slurry appearance and decreased Chl *a* was observed, particularly in relation to the colour of the mixed liquor, which transitioned from green to a brownish-olive green during the 20 days cultivation (Plate 3.2 & 3.3)

Particulate organic carbon (POC)

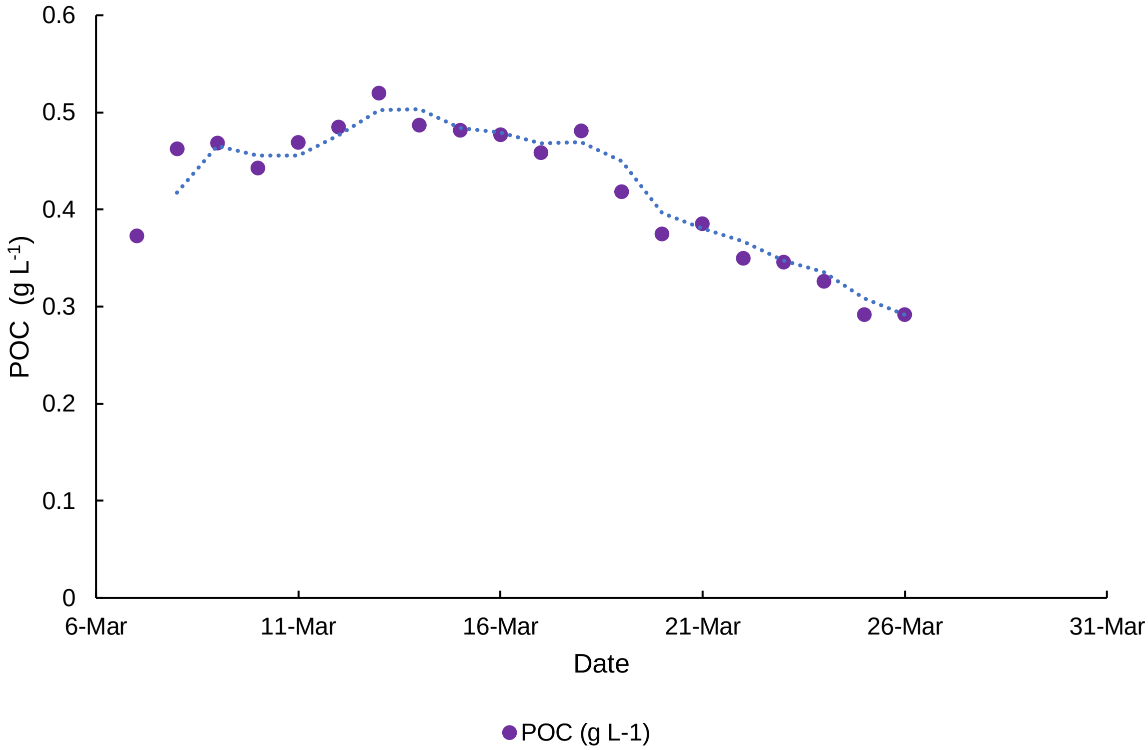

Figure 3.14 Algae grown in 10% aerobic reactor effluent: Particulate organic carbon (POC)

POC concentrations reflecting algal growth also gradually decreased from 0.37 to 0.29 g L^{-1} POC (Figure 3.14)

Nutrient composition

The N and C concentrations of the HRAP mixed liquor were monitored over the 20d cultivation period.

NH_4^+-N levels at the start of the experiment were 0.09 and gradually decreased to 0.06 g L^{-1} NH_4. Nitrification of the wastewater in the HRAP was significant (Fig.3.15). The amount of NO_3-N exceeded the total of NO_3-N and NH_4-N at the start of the experiment; suggesting either conversion of organic -N (not measured) to NH_4-N. This is supported by the mineralisation of TOC to IC over the duration of the trial (Fig 3.16). The total organic carbon in the wastewater was converted to inorganic carbon (IC) by microorganisms and made available for algal photosynthesis.

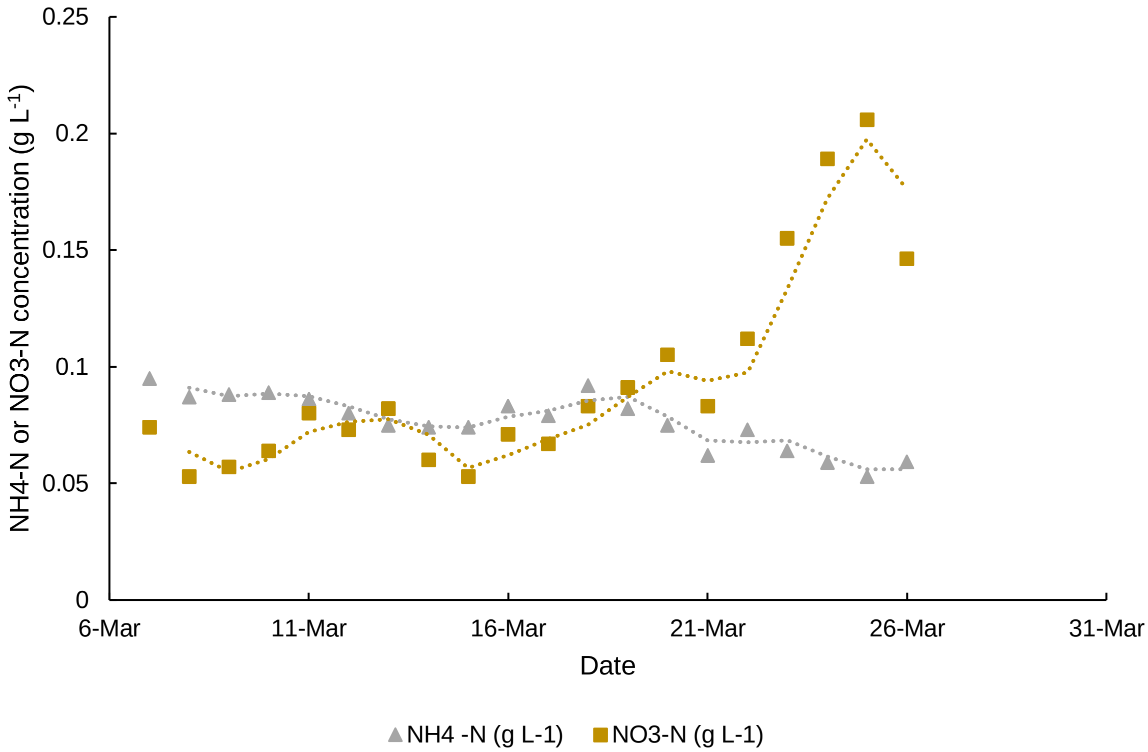

Figure 3.15 Algae grown in 10% aerobic reactor effluent: ammonium (NH_4-N) and nitrate (NO_3-N) in the HRAP treated wastewater.

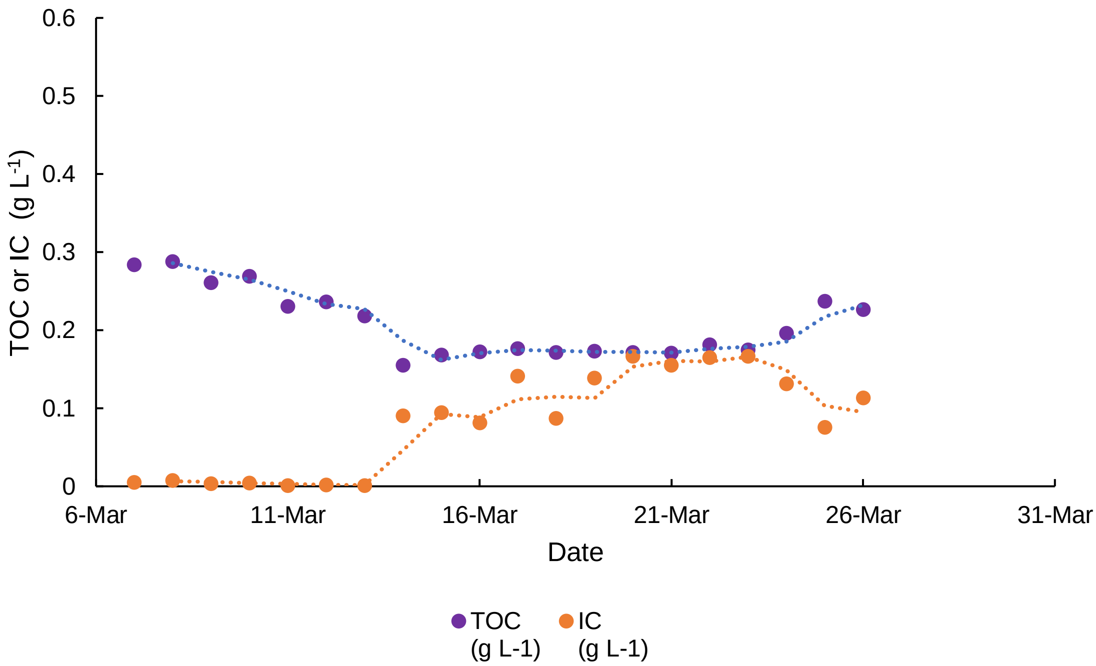

Figure 3.16 Algae grown in 10% aerobic reactor effluent:Total organic carbon (TOC) and inrganic carbon (IC) in the treated wastewater

Plate 3.2 Wastewater treated in the aerobic reactor at a 10d THRT entering the HRAP at the start of Trial 2.

Plate 3.3 HRAP at the commencement (left) and completion (right) of Trial 2.

E. coli removal

Anaerobically pre-treated pig slurry had an *E.coli* inlet concentration of 5.21 $\log_{10}$ MPN 100 mL^{-1}. After aerobic treatment at a 10 d THRT, the concentration was significantly reduced to 3.28 $\log_{10}$ *E.coli* MPN 100 mL^{-1}, a 1.93 $\log_{10}$ reduction. Combination with HRAP treatment (20 days), achieved a total $\log_{10}$ reduction of 3.09, indicating a significant improvement in the microbiological quality of the treated effluent (Table 3.3).

Table 3.3 ***E.coli*** **concentraion and $\log_{10}$ reduction value in anaerobic pond effluent (inlet), aerobic reactor (AR) effluent treated constant oxygen concentration (3-4mg O_2 L^{-1}) at a 10d THRT and after 20d growth in a HRAP.**

	Escherichia coli **concentration ($\log_{10}$ MPN 100 mL^{-1})**			***Escherichia coli*** **Log_{10} reduction values**		
	Inlet	**AR**	**HRAP**	**AR (10d)**	**HRAP (20d)**	**Total**
n	1	10	20	-	-	-
Mean	5.21	3.28	1.67	1.93	1.16	3.09
Standard deviation	0.00	0.18	0.21	0.18	0.21	-
Median	5.21	3.34	1.68	1.88	1.16	3.03

3.9.4 HRAP trial 2: Algal growth over 7 d in (50 % v/v) of aerated ANPS treated at a 10d THRT

At the end of Trial 1 (above) half the pond volume of wastewater was discharged and replaced with treated effluent from the aerobic reactor (10d THRT, 3-4 mgO_2 L^{-1}). The algal population from Trial 1 serving as an inoculum for Trial 2.

Table 3.4 Algal growth in (50 % v/v) treated aerobic reactor effluent: Wastewater composition.

Wastewater composition	**NH_4-N ($g\ L^{-1}$)**	**NO_3-N ($g\ L^{-1}$)**	**pH**	**Cond ($\mu S\ cm^{-1}$)**	**TOC ($g\ L^{-1}$)**	**TC ($g\ L^{-1}$)**	**IC ($g\ L^{-1}$)**	**TSS (g L-1)**	**Chl *a* (mgL-1)**
Trial 2 initial	0.04	0.03	8.38	2894	0.24	0.35	0.11	0.49	0.49
Trial 2 final	0.02	0.07	7.93	2242	0.23	0.34	0.11	0.60	0.64

Chlorophyll a and total suspended solids

The chlorophyll *a* concentration at the start of Trial 2 was 0.49 mg L^{-1} (Table 3.4). Throughout the 7 days cultivation the Chl *a* concentration gradually increased to 0.64 mg L^{-1} (Fig. 3.17). Similarly, the total suspended solids also increased significantly from 0.37 to 0.6 mg L^{-1} (Fig. 3.17). The particulate organic carbon (POC) increased from 95mg L^{-1} to 137 mg L^{-1} over the first 5d of cultivation then plateaued (Fig.3.18). The increases in chlorophyll *a*, TSS and POC clearly demonstrated algal biomass production in this wastewater.

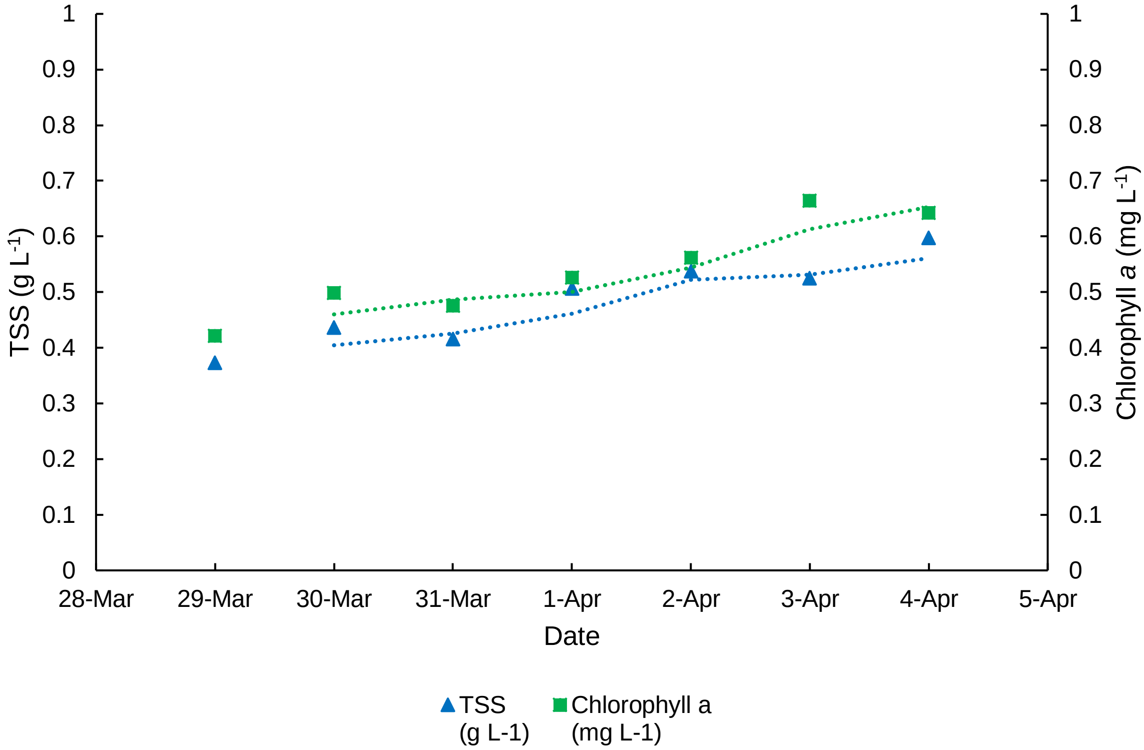

Figure 3.17 Algae grown in 50% aerobic reactor effluent:Chlorophyll *a* and total suspended solids (TSS) concentration in the treated wastewater over 7d cultivation.

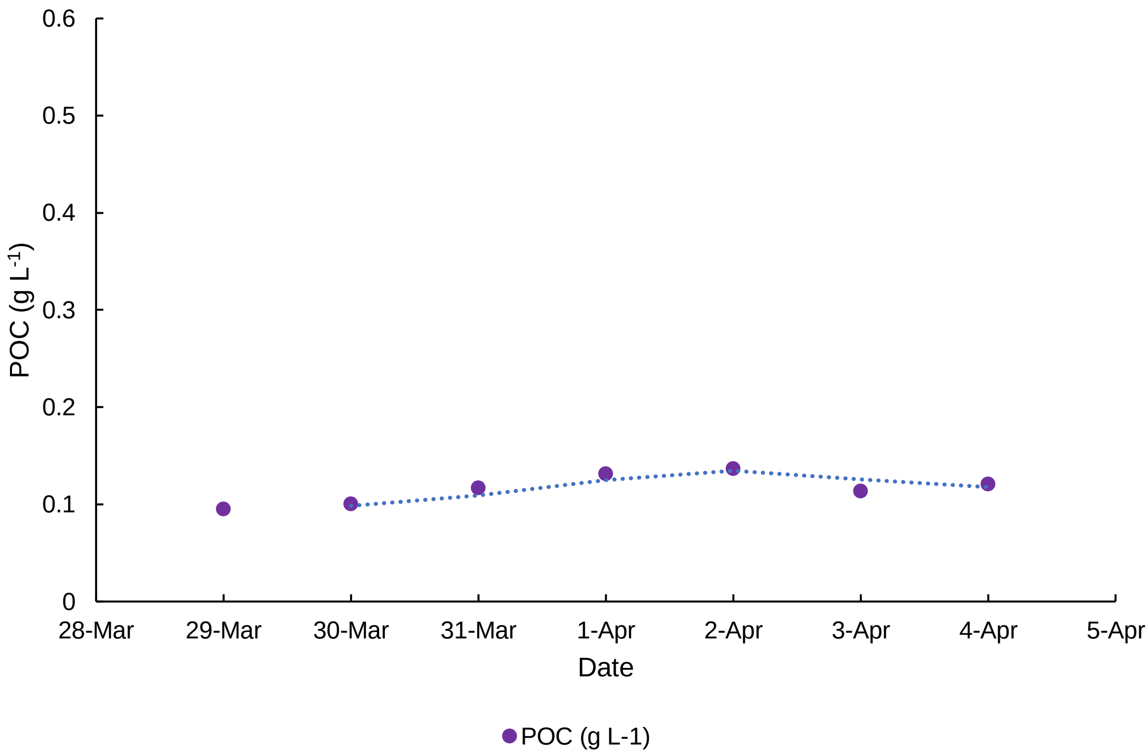

Figure 3.18 Algae grown in 50% aerobic reactor effluent:Particulate organic carbon (POC) concentration in the treated wastewater over 7d cultivation.

Nutrient composition

Nitrate was the predominant source of nitrogen for algal growth in the highly nitrified effluent from the aerobic reactor. The concentration of NO_3-N decreased from 117 to 65 mg NO_3-N L^{-1} over the 7 d of the batch culture. Similarly, although significantly lower initially, the NH_4^+-N concentration decreased from 30 to 20 mg NH_4-N L^{-1} over the same period (Fig. 3.19).

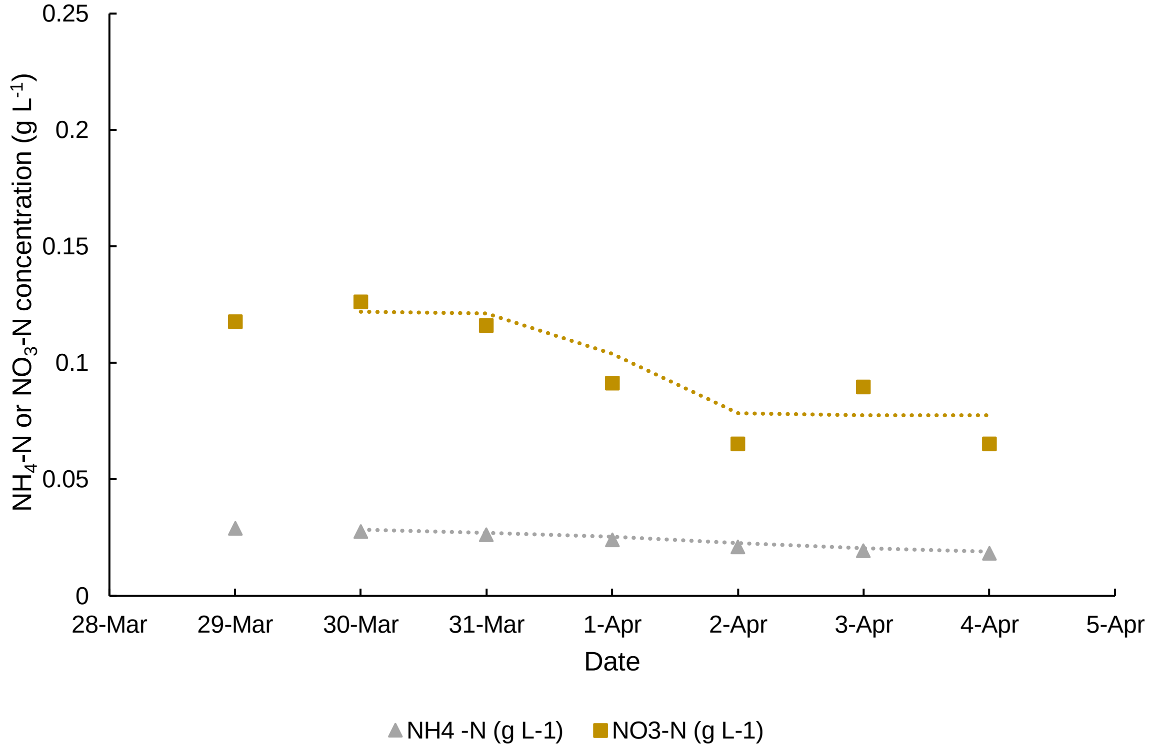

Figure 3.19 Algae grown in 50% aerobic reactor effluent: Ammonium (NH_4-N) and nitrate (NO_3-N) concentration in the treated wastewater over the 7d cultivation.

The initial TOC concentration of the wastewater was lower than that measured for Trial 1, suggesting more mineralisation had occurred during aerobic treatment and subsequent storage. There was little significant change in TOC or IC during Trial 2 (Fig. 3.20). The change in colour of the effluent following treatment in the HRAP is shown in Plate 3.4. The microalgae consortium found under microscope examination appeared to be predominately *Chlorella sp*. And *Scenedesmus sp*. which is also found in the Kingston-on-Murray HRAP effluent (Plate 3.5).

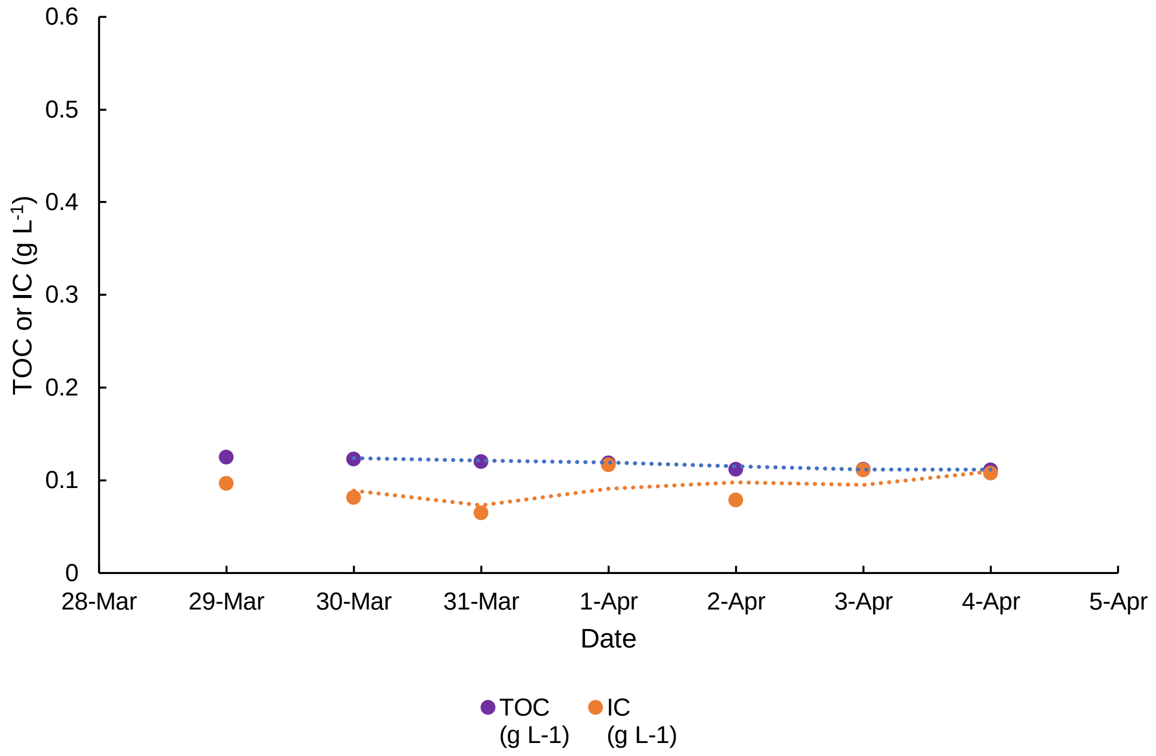

Figure 3.20 Algae grown in 50% aerobic reactor effluent: Total organic carbon (TOC) and inorganic carbon (IC) concentration in the treated wastewater over the 7d cultivation.

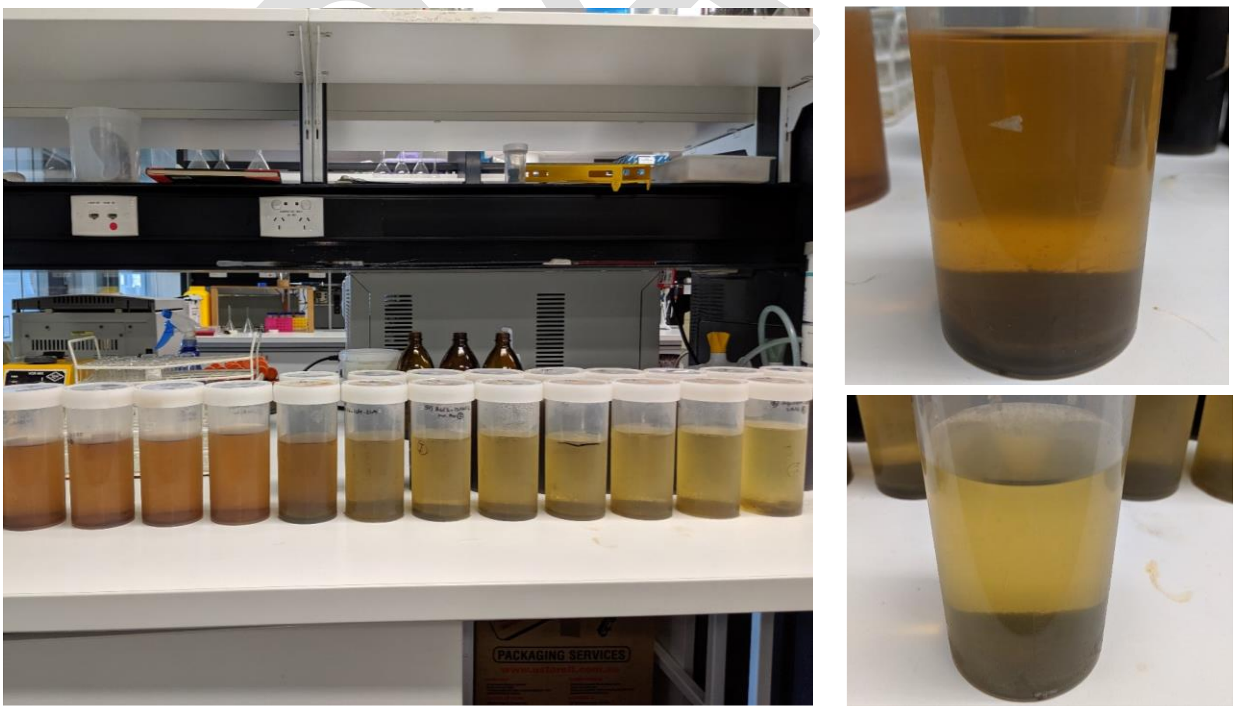

Plate 3.4 Initial colouration of the mixed liquor was changed from a brownish-orange (top right) to a light green (bottom right) after 7 days cultivation

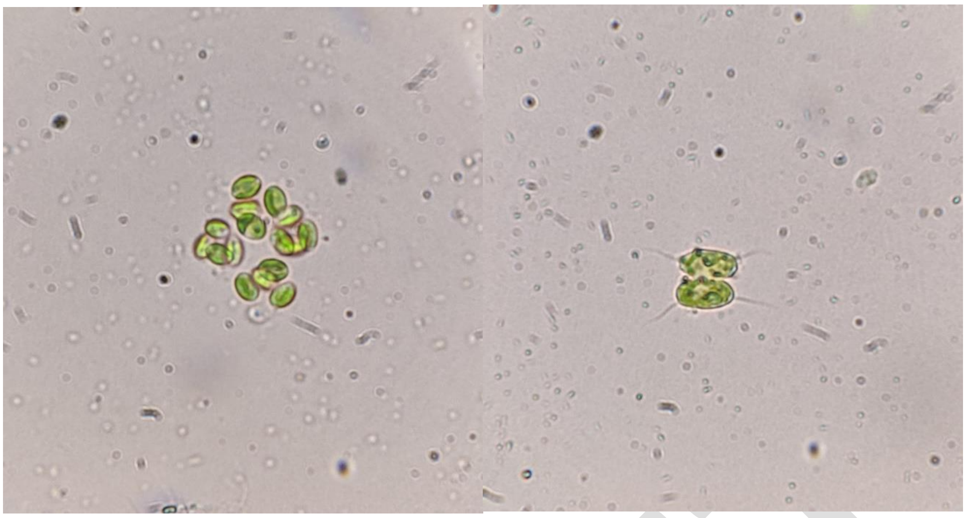

Plate 3.5 Microalgae consortium of *Chlorella sp.* (left) and Scenedesmus sp. (right) were found in the HRAP by using the aerated ANPS (x1000 magnification).

4 DISCUSSION AND CONCLUSION

The report presents the results of field trials conducted from January to April 2019 to address the milestone:

> *HRAP operation conditions determined to maximise algal biomass energy production and disinfection of water for reuse in piggery operations. Evaluation of the performance of the iWWTP.*

This report should be read with reference to the previous report, *4a-105 - Aerobic and algal treatment of piggery wastewaters for heat recovery, effluent treatment and water reuse (*Fallowfield and Cheng, 2018).

Aerobic treatment performance

The $10m^3$ aerobic reactor (AR) was operated to maintain a dissolved oxygen concentration of 3 – 4 mg O_2 L^{-1} (the setpoint) initially at a theoretical hydraulic retention time (THRT) of 5d to reduce treatment time and increase the rate of treated effluent production for the HRAP trials. Attainment of a steady state requires operation over at least 3 hydraulic retention times i.e. 15d. Since provision of a nitrified effluent for the algal growth trials was considered a priority this configuration was abandoned in favour of operating the reactor under the conditions recommended by Hawley (2019). Future aerobic reactor research should further investigate a range of THRTs.

The THRT of the aerobic reactor was increased to 10d and operated at the same DO setpoint (3 – 4 mg O_2 L^{-1}) over 28d. This duration is approaching that required to achieve steady state. Operation in this configuration achieved >50% TSS reduction, high rates of nitrification, resulting in retention of nitrogen for algal growth in the treated effluent, and a 50% reduction in ammonium concentration. The removal of ammonium (NH_4-N) reduces the potential to produce phytotoxic free ammonia (NH_3-N) at the higher pH obtaining in a HRAP in the daytime – a consequence of algal photosynthesis. Furthermore, reuse of a treated effluent, low in ammonia, for shed flushing is likely beneficial for pig health since ammonia released during flushing operations has been shown to sensitise the pig lung to opportunistic pathogens increasing the time to attain slaughter weight (Murphy et al, 2012).

Inorganic carbon comprised > 60% of the total carbon in the treated effluent. This indicates that there was sufficient mineralizable organic carbon available in the anaerobically pre-treated effluent to 'drive' nitrification in the aerobic reactor. Furthermore, following aerobic treatment there was also inorganic carbon for algal growth and photosynthesis in the HRAP.

The treatment performance of the pilot scale AR confirmed the laboratory results of Hawley (2019).

At steady state, operated at a mixed liquor volume of $10m^3$ at a 10d THRT and a DO setpoint of 3 – 4 mg O_2 L^{-1}, the calculated energy consumption for aeration was 2.53 kW d^{-1}. The use of a submerged aerator allowed recovery of heat energy from its operation. This, together with the release of metabolic energy and adsorption of radiant energy, resulted in the temperature of the aerobic reactor mixed liquor being 9ºC above ambient air temperature. A heat exchanger and heat pump could be used both to recover this heat energy and upgrade the temperature of water for piggery operations. However, aerobic treatment of raw slurry, which releases more metabolic energy, with heat recovery is likely to be the more economic approach and is worthy of future research.

Growth of algae in the high rate algal pond

An algal inoculum was readily established in the HRAP operated at 03.m depth using 5% (v/v) of the effluent from the aerobic reactor operated at a 10d THRT.

This inoculum (1.21 mg chlorophyll *a* L^{-1}) was then used in a trial operated over 20d using 10% (v/v) aerobic reactor effluent. The chlorophyll *a*, TSS and POC of the initial algal biomass was maintained over the 20d of the batch culture, however, there was an unexpected steady decline in all biomass parameter towards the end of the trial period. The decline was unlikely due to ammonia toxicity since the ammonium concentration was < 100 mg L^{-1}. Interestingly, the decline in algal biomass was at a time when high rates of nitrification were observed in the culture, raising the possibility that the decline in algal biomass was associated with competition between nitrifying bacteria and algae for inorganic carbon during the period of increased nitrification. Light availability for algal photosynthesis may also have influenced the decline. Elevated wastewater turbidity (colour and suspended solids) adversely affect light penetration and availability for photosynthesis. Light attenuation is influenced by the natural turbidity of the wastewater and by the algal biomass – high concentrations leading to light limitation of the culture due to 'self-shading' of algal cells. The initial inoculum may have been too concentrated reducing light availability and while it maintained, growth could not occur under the imposed culture conditions.

The microbiological quality of the wastewater was improved significantly following treatment of the anaerobic pond effluent by the integrated aerobic-algal system. Treatment in the aerobic reactor achieved almost 2 $\log_{10}$ reduction in *E.coli,* followed by a further 1.2 $\log_{10}$ reduction in the HRAP. Overall there was a 3 $\log_{10}$ reduction in *E.coli* numbers following integrated treatment (controlling for the dilution of effluent in the HRAP). *E.coli* is a recognised treatment performance indicator and is also used as a surrogate for the behaviour of bacterial pathogens. The reduction of recognised and opportunistic pathogen load in wastewaters destined for reuse in piggery operations, coupled with the associated reduction in ammonia concentration, will improve the pork production environment. The availability of higher quality wastewater for reuse has the potential to improve pig health, decrease the time to slaughter weight and reduce associated feed costs. Further research on pathogen and ammonia removal by the integrated treatment system is recommended with the objective of improving the production environment and pig health. Research on the behaviour of multiple antibiotic resistant bacteria in the integrated system is also warranted.

A second growth trial was conducted using 50% (v/v) aerobic reactor effluent. The effluent was from the near steady state treatment at a 10d THRT. The algal biomass from the 20d (10%) AR effluent trial (above) was used as inoculum. It is worth noting that the chlorophyll a concentration of this inoculum was a third that used in the previous 20d trial. Time constraints meant that this culture could only be operated for 7 day. Algal growth in this effluent was clearly demonstrated, evidenced by increases in chlorophyll *a*, total suspended solids and particulate organic carbon concentrations. NO_3-N was the nitrogen source for growth.

Constraints

It was agreed that research would be of 3 months duration. Aerobic reactor and high rate algal ponds operate at relatively long hydraulic retention times e.g. 10d. It is recognised that at last 3 hydraulic retention times are required to attain close to steady state –a quasi steady state given concomitant environmental changes (temperature, light) which influence HRAP performance. This limits the number and duration of operational scenarios which can be evaluated in the time available. Notwithstanding the performance of the aerobic reactor on 10 THRT over 28 days most likely reflects the performance of the AR under these conditions.

Operational issues were identified with operation of the pilot plant, which affected operation. Backflow of wastewater occurred between AR, the separator and inlet receival tank after pumping transfers. This is due to liquid head differences between tanks. It can be rectified by retrofitting one-way flow valves activated at the commencement of the pumping cycle. Backflow meant that the sedimentation tank could not be used to remove suspended solids from the effluent following treatment in the aerobic reactor. This resulted in an effluent with higher suspended solids concentration being delivered to the HRAP. There was also no opportunity to return a percentage of the settled solids, rich in nitrifying bacteria, to the aerobic reactor to determine if this would improve treatment performance – the proposed return activated sludge mode of operation.

Addressing the backflow issues would lead to improvement in removal of NH_4-N via increased nitrification. Algal growth would benefit from enhanced solid separation improving light penetration and availability algal biomass production.

Conclusions

- The aerobic reactor fed anaerobically pre-treated slurry, operated at 10d THRT at a constant 3 – 4 mg O_2 L^{-1} achieved >50% reduction in both total suspended solids and NH_4-N the latter through high rates of nitrification.
- The energy consumption of this reactor at steady state was 2.53 kW d^{-1}.
- Algal growth occurred in a batch culture containing 50% of the treated effluent from the aerobic reactor.
- Passage through the integrated system resulted in a 3 $\log_{10}$ reduction of *E.coli*
- Further research is warranted on the integrated system with regards to ammonium and pathogen removal in wastewater destined for reuse; to improve the quality of the production environment, pig health and the economics of pork production.

5 ACKNOWLEDGEMENTS

We would like to acknowledge the support of the Roseworthy Piggery Manager Simon Go who modified the summer desludging process to enable our research to continue. Raj Indela, College of Science and Engineering and David Hart, Dematec Ltd for technical support.

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