Potential biogas scrubbing using a high rate pond

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Abstract The potential to scrub biogas in a high rate pond (HRP) was evaluated using apparatus designed to maximize gas–liquid contact. Experiments compared the removal of carbon dioxide from synthetic biogas by an “in-pond angled gutter” to that by a simulated “counter-current pit.” Results showed that the counter current pit has potential for use in biogas scrubbing, with synthetic biogas carbon dioxide composition consistently reduced from 40% to < 5%. The in-pond angled gutter was less effective due to bubble coalescence which reduced the total bubble surface area available for gas transfer. Measurement of oxygen levels in the scrubbed biogas showed that despite supersaturation of oxygen in the HRP water, there was little transfer to the biogas, so that explosive methane/oxygen mixtures would not be formed. Theoretical calculations indicated that the amount of biogas likely to be formed during anaerobic treatment of municipal wastewater could be scrubbed in the HRP of the same advanced pond system with little influence on HRP pH, algal growth and treatment performance. These encouraging results justify further research on this method of biogas purification.

Keywords Biogas scrubbing; carbon dioxide; greenhouse gas; hydrogen sulphide; methane; pH; high rate pond

Introduction

Advanced pond systems include initial anaerobic treatment typically in either an anaerobic pond or advanced facultative pond, followed by aerobic treatment in a high rate pond (HRP) and subsequent pond stages. The biogas produced in the anaerobic stage could potentially be collected for power generation (e.g. Green et al., 1995). However, the biogas may require scrubbing to prevent hydrogen sulphide corrosion of engines, pipelines and biogas storage structures, and to improve engine efficiency by reducing the carbon dioxide concentration (e.g. Metcalf and Eddy, 1991; Huang and Crookes, 1998).

Biogas is usually scrubbed using chemical methods, but scrubbing biogas with HRP water could avoid the use and disposal of expensive chemicals. In this study we investigated biogas scrubbing using two simple apparatus to improve gas–liquid contact and thus gas transfer: an “in-pond angled gutter” (Figure 1) and a “counter-current pit” (Figure 2). Because algal photosynthesis in HRPs can result in dissolved oxygen levels exceeding 300% saturation, oxygen levels in the final purified gas were measured, to assess the transfer of oxygen into the biogas and evaluate the apparent potential for explosive methane/oxygen mixtures to form.

HRP have high daytime pH from assimilation of dissolved carbon dioxide by algae during photosynthesis. Elevated pH may have a negative feedback by reducing algal assimilation of carbon dioxide and growth (e.g. Azov, 1982; Azov et al., 1982). However, high pH augments a number of treatment processes in the HRP, including nutrient removal (by phosphorus precipitation and ammonia volatilisation) and disinfection (Nurdogan and Oswald, 1995; Davies-Colley et al., 2003). Thus, significant lowering of HRP pH associated with carbon dioxide addition from biogas may adversely affect these processes, but could improve algal growth and nutrient assimilation. Theoretical calculations were made to examine the potential effects of biogas carbon dioxide addition on HRP pH.
Methods

Practical experiments

Two angled gutters (PVC, 3.75% slope, 5 m and 8 m long) were placed within a pilot-scale HRP at the Ruakura Research Facility, Hamilton, New Zealand. A 1 m deep counter-current pit was simulated using a 1 m vertical column (50 mm polycarbonate and PVC pipe) down which HRP water was pumped at a fluid velocity of 15 cm/sec (the horizontal velocity of water in a typical HRP). Both apparatus were evaluated for their ability to remove carbon dioxide from synthetic biogas (40% carbon dioxide, 60% nitrogen). Gas was sparged into each apparatus using an aquarium sparging stone, with gas flow rates fixed at various levels between 250 and 2000 mL/min using a calibrated rotameter. Bubble behaviour was observed and exit gases were collected in 600 mL Tedlar gas bags (Alltech Ltd.) for analysis of carbon dioxide (Draeger tube method CH20301, 5–60% CO2) and a 250 mL floating gas collector for oxygen measurement (TPS WP-82Y meter with YSI 5739 probe). All gas measurements were carried out in triplicate. The pH, temperature and DO of the HRP water was measured during all experiments, which were carried out during the afternoon (when HRP pH is high) in March 2003 (NZ autumn).

Theoretical calculations

Estimation of biogas production. Assuming a typical volatile suspended solids (VSS) concentration in raw wastewater of 180 g/m³ (75% of total suspended solids (TSS) 240 g/m³) and multiplying by values of typical biogas production from anaerobic treatment, (0.5–1.5 m³ biogas/kg VSS) (e.g. Hobson et al., 1981; Metcalf and Eddy, 1991) gives 0.09–0.27 m³ biogas/m³ wastewater. Assuming HRP of the APS system has an 8-day residence time, the relationship of daily potential biogas production (in the upstream anaerobic pond) per m³ of volume in the HRP is calculated by dividing these values by 8 which gives 0.011–0.034 m³ biogas/m³ HRP volume.

Prediction of pH change. The PHREEQC computer chemical equilibrium model was used to predict changes in pH due to biogas carbon dioxide addition. Major ion concentrations in the HRP water measured on several samples using HPIC and bicarbonate titrations and average NH4-N and DRP concentrations from routine monitoring data measured using Standard Methods (APHA, 1998) were used as the model inputs. Starting pH for the modelled HRP water was 9.5 (typical of afternoon pH levels measured in the Ruakura HRPs). The model was set to maintain ionic equilibrium using pH. Carbonate
concentrations in the modelled HRP water were increased by amounts equivalent to the number of moles of carbon dioxide contained in the daily biogas production, assuming biogas carbon dioxide concentrations of both 20% and 40%.

Results and discussion

Practical experiments

Upright column: bubble behaviour and carbon dioxide removal. Gas flow rates below 750 mL/min in the upright column resulted in small (2–6 mm diameter) bubbles that were carried away with the downward flow of the pumped HRP water. In practice this would represent loss of valuable methane. Higher gas flow rates resulted in larger (6–10 mm diameter) bubbles that had sufficient buoyancy to slowly rise up the column for collection. Results from exit gas carbon dioxide analysis for gas flow rates between 750 and 2000 mL/min (Table 1) showed that this apparatus has potential for use in biogas purification. Concentrations of carbon dioxide in the purified gas were consistently reduced to less than 5% (the detection limit of the method used) even with gas flow rates up to 1500 mL/min.

Angled gutter: bubble behaviour and carbon dioxide removal. Bubble coalescence in the angled gutters seemed to reduce the extent and consistency of carbon dioxide absorption. The amount of coalescence increased as the gas flow rate was increased. Concentrations of carbon dioxide in the exit gas from the 5m gutter rose from 10% to 24% with increasing gas flow (Table 1). Coalescence of the bubbles (reducing bubble surface area per unit gas volume) as they rose along the gutter reduced the extent of carbon dioxide absorption occurring in the latter length of the gutter. Thus, the longer 8 m gutter (data not shown) did not perform significantly better than the 5 m gutter. Gas flow rates above 1000 mL/min led to large bubbles spilling out from underneath the apparatus.

Oxygen levels in exit gas. Mixtures of methane and pure oxygen are explosive at between 5% and 60% methane content (e.g. Strahle, 1993). The results for carbon dioxide absorption and oxygen desorption shown in Table 1 suggest that exit gas composition would be in excess of 60% methane, and therefore too rich a mixture to combust without the provision of additional oxygen.

Theoretical calculations

Changes in HRP pH due to biogas carbon dioxide addition. Results for PHREEQC modelling of the decrease in HRP water pH with carbon dioxide addition are shown in Table 2. At the maximum amount of biogas carbon dioxide added, HRP pH decreased from 9.5 to 8.7. Because PHREEQC modelling does not take into account the complex and interactive nature of HRP wastewater treatment processes (e.g. Moutin et al., 1992;
Mesple et al., 1996), no attempt is made here to interpret PHREEQC output data in terms of wastewater treatment. However, the relatively low decreases in pH predicted by these calculations lessen concerns over potential reductions of HRP wastewater treatment due to decreased pH, and justify further research into biogas scrubbing in a HRP. The small decline in HRP pH also suggests that any increase in algal biomass concentration as a result of biogas carbon dioxide addition is likely to be minor.

Conclusions

These experiments indicate that the counter-current pit apparatus has the potential to be used for in-pond biogas scrubbing and should be explored further. The angled gutter apparatus was ineffective due to bubble coalescence. Oxygen mass transfer from the HRP water into the gas phase did not lead to the formation of explosive methane/oxygen mixtures under the conditions tested. Chemical equilibrium modelling indicated that the amount of biogas likely to be formed during anaerobic treatment of municipal wastewater could be scrubbed in a HRP with minor effects on HRP pH and algal growth, and thus HRP performance. The encouraging results of this study justify further research into this method of biogas purification.

References


Table 2 PHREEQC model outputs of changes to pH after addition of biogas CO₂ to the HRP

<table>
<thead>
<tr>
<th>m³ biogas / m³ HRP</th>
<th>pH at 20% CO₂</th>
<th>pH at 40% CO₂</th>
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<td>0.03</td>
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<td>9.3</td>
</tr>
<tr>
<td>0.00</td>
<td>9.5</td>
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