IN-Situ Methane Enhancement System using Differential Solubility of Biogas

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1. INTRODUCTION

The offgas from anaerobic digesters typically contains 50~60 percent CH₄, 35~45 percent CO₂ and less than 1 percent H₂ and H₂S. One of the most significant cost factors is the purification of biogas to meet pipeline quality greater than 95% CH₄. The cost of CO₂ separation alone amounts to about $3.50 to $5.00 per GJ, depending on the technique used and the scale of operation. The physico-chemical techniques for the purification of biogas include molecular sieve and membrane separation, pressure swing absorption/desorption, chemical absorbents, etc. A concept first described by Heyes and Issacson(1984) utilizes phase separation, with a first phase reactor at a pressure of 1 atm and a temperature of 35°C, and a second phase reactor at a pressure of 2 atm. The combination of low pressure and low pH in the acetogenic first phase reactor decreases CO₂ solubility, producing high CO₂ offgassing. Conversely, the high pH and increased pressure of the methanogenic phase reactor results in high CO₂ solubility and low CO₂ offgassing, resulting in higher CH₄ content. Experiments conducted in this study were based on the differential solubility of CH₄ and CO₂ under ambient pressure(Jewell et al.1988). At a pH of 7.0 and 35°C, for example, CO₂ is 40 times more soluble than methane. An aqueous stream entering a reactor that is not saturated in CO₂ will have a capacity to absorb a significant portion of the CO₂ produced in the anaerobic conversion of organic matter, but will absorb a small fraction of the insoluble methane. This difference in solubility in biogas leads a partial separation of the CO₂ from the biogas stream. The amount of CO₂ absorbed in the aqueous phase of a digester is influenced by a number of factors such as temperature, partial pressure, pH, influent stream CO₂, alkalinity and ionic strength. The objective of this study was to develop a simple in-situ technique to enhance digester offgas methane content by using the differential solubility of biogas at the mesophilic temperature.

2. METHODS

Methane Enhancement System

Methane Enhancement System in this study were a low solids plug-flow sorghum digester coupled by a leachate recycle loop to an external stripper(Kang et al. 1998). As shown in Fig. 1, leachate containing dissolved carbon dioxide was recycled from the plug-flow sorghum digester to a stripper, which removed the dissolved CO₂ by stripping with nitrogen. Leachate, now free of CO₂, was then recycled from the stripper to the anaerobic plug-flow digester.

Quantitative evaluation of system variables defined the effects of leachate recycle rate(LRR) and reactor alkalinity on the resulting offgas methane contents and the total volatile solids(TVS) removal efficiency.

A summary of experimental conditions for methane enhancement system is presented in Table 1.

Substrate

Sorghum, a candidate energy crop, was the feedstock used throughout the experiment. Analysis and composition are given in detail elsewhere(Kang et al. 1990). Whole plants(excluding grain) were field chopped and ensiled. Prior to use, they were rapidly air dried to prevent spoilage. The sorghum had a significant soluble organic fraction that was rapidly degradable with rates peaking approximately 6 hours after start-up.
Table 1. Summary of experimental conditions for methane enhancement

<table>
<thead>
<tr>
<th>Conditions</th>
<th>OLR (gVS/ L-d)</th>
<th>SRT (days)</th>
<th>T.Alk. (g/L as CaCO₃)</th>
<th>Leachate Recycle Rate (v/v-d)</th>
<th>Sweep Gas</th>
<th>Stripper Gas Flow Rate (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Reactor</td>
<td>2.0</td>
<td>52</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Methane Enhancement</td>
<td>2.0</td>
<td>52</td>
<td>2.0</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Reactor (35 °C)</td>
<td>4.0</td>
<td>2.0</td>
<td>1.0</td>
<td>2.0</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>6.0</td>
<td>4.0</td>
<td>1.0</td>
<td>2.0</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>8.0</td>
<td>4.0</td>
<td>1.0</td>
<td>2.0</td>
<td>2.0</td>
<td>-</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

Offgas CH₄ contents correlated well with LRR as shown in Fig. 2. However excessively high recycle rates led to digester pH levels above 8.7, resulting in inhibition of methanogenesis and lowered CH₄ production. However the total volatile solids(TVS) removal efficiency was decreased as LRR increased(e.g., 90% TVS removal efficiency at LRR 1 was dropped to 70% TVS removal efficiency at LRR 4) as shown in Fig. 3. 

Due to leachate liquid flow limitation, CH₄ production rates of the methane enhancement system were limited to the range of 0.8~1.0v/v-d under all paralled conditions as shown Fig. 4. However this CH₄ production rates showed 118~152% higher than that of the control reactor.

For practical purposes, the application for plug-flow typed Semi-Continuously Fed and Mixed Reactor(SCFMR) is limited to relatively low solid systems, with solids that are easily separated from the leachate stream. Hence, the leachate moves through the solid mass at a relatively slow rate and the solids must separate in the methane enhancement reactor. The maximum digester solids concentration is approximately 6 to 8% dry matter for the methane enhancement system.

It is likely that the optimum recycle rate was 3 volume of leachate recycle per volume of reactor per day(3v/v-d) at the reactor alkalinity of 4 g/L as CaCO₃, which resulted in offgas CH₄ contents of over 94%.

Fig. 2 Effect of leachate recycle rates on biogas methane contents at mesophilic condition with N₂ gas
4. SUMMARY AND CONCLUSION

A simple in-situ technique to enhance digester offgas methane content was developed by using the differential solubility of biogas at the mesophilic temperature. The methane enhancement systems were low solid plug flow sorghum digester coupled with a recycle loop to an external stripper. Quantitative evaluation of system variables defined the effects of leachate recycle rate (LRR) and reactor alkalinity on the resulting offgas methane contents and the total volatile solids (TVS) removal efficiency. The results show that offgas methane contents over 94% were observed at the reactor alkalinity of 4 g/L as CaCO$_3$ and at the LRR of 3 volume of leachate recycle per volume of reactor per day (3 v/v-d). The total volatile solids removal efficiency appeared 79% which was 94% of the control reactor. Offgas methane contents correlated well with the leachate recycle rates. However excessively high LRR led to digester pH levels above 8.8, resulting in inhibition of methanogenesis and lowered biogas production.

REFERENCES