The Benefits of Biogas Conditioning

Alisa Wiebe
Product Development, Biorem Technologies Inc.,
7496 Wellington Road 34, RR#3, Guelph, Ontario, N1H 6H9
Email: awiebe@biorem.biz

ABSTRACT
Anaerobic digestion is quickly becoming the choice technology for sewage sludge treatment at wastewater treatment plants, as the methane rich biogas produced is a valuable resource which can be used to generate electricity. In the oxygen restricted environment, a natural by-product of the anaerobic process is hydrogen sulfide, a harmful contaminant. Also present in the biogas are organosilicons, or siloxanes, which originate from cosmetic products. Efficient removal of these compounds is essential to support economic recovery and use of the biogas. This paper discusses various technologies and the benefits and economics of biogas conditioning.

KEYWORDS
Biogas, Hydrogen Sulfide, Siloxanes, Conditioning, Benefits of Conditioning

INTRODUCTION

Biogas Production at Wastewater Treatment Plants
Treatment of wastewater in municipalities consists of a screening process, primary settling and secondary treatment, all of which remove solids from the wastewater. The solids from primary and secondary treatment, referred to as sewage sludge, require further treatment before disposal in landfills or agricultural land application. As wastewater treatment plants become larger, the quantity of sludge produced requires a more extensive treatment than aerobic digestion or composting, both of which have low capital costs but higher operating costs due to the energy costs associated with aeration. Anaerobic digestion can easily be designed to handle higher loadings of sludge and after processing produces a small quantity of biosolids.

Anaerobic digestion is the decomposition of organic material in the absence of oxygen. Depending on the operating temperature, retention times vary from 12-40 days, which allows a variety of bacteria to breakdown the organics into essentially methane (CH₄), carbon dioxide (CO₂) and water (H₂O). Due to the physical properties of these compounds, they form a gaseous mixture, biogas, consisting of 40-70% methane.

In addition to carbon, hydrogen and oxygen molecules, sewage sludge also contains organic sulfur from feces and inorganic sulfur from sulfate ions present in the water. Under anaerobic conditions, sulfate reducing bacteria produce hydrogen sulfide (H₂S), which volatilizes into the biogas.

As siloxanes become an increasingly popular compound in cosmetics such as shampoos and conditioners, they are also being identified in higher concentrations in wastewater. In the anaerobic digestion process the siloxanes volatilize into the biogas.
Table 1: Composition of Biogas

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>40 – 70%</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>25 – 40%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0 – 5%</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0 – 2%</td>
</tr>
<tr>
<td>Hydrogen Sulfide</td>
<td>0 – 2% (20,000 ppm)</td>
</tr>
<tr>
<td>Total Siloxanes</td>
<td>0 – 150 ppm</td>
</tr>
<tr>
<td>Water</td>
<td>RH 100%</td>
</tr>
</tbody>
</table>

**Biogas Utilization**

Because of its high methane content, biogas is comparable to natural gas and can therefore be burned to produce energy. One of the most common ways to utilize the biogas is in an internal combustion engine. The electricity produced in the engine can be used to supplement electricity requirements within the plant or can be sold to the electrical grid. Either way, the biogas is a revenue source for the plant.

To increase the efficiency further, heat can be recovered off the engine, its exhaust, and the oil. This heat can be used to heat the digesters or in other areas of the wastewater treatment plant.

Both hydrogen sulfide and siloxanes have damaging effects on the engine components and equipment.

**Hydrogen Sulfide & Siloxanes**

Hydrogen sulfide is the cause of a number of problems:

- **Acidification**
  Hydrogen sulfide can react with water to form sulfuric acid. Sulfuric acid affects the engine oil by lowering its pH, which increases the frequency of oil changes.

- **Corrosion**
  The formation of sulfuric acid can corrode metallic components throughout the treatment equipment and in the engine, such as the engine cylinders and pistons. Once piping and equipment starts to corrode, it must be replaced to prevent leaks of the biogas to atmosphere.

- **Emissions**
  Hydrogen sulfide present in the biogas will combust to form sulfur oxides (SOx) impacting emission quality and potentially increasing costs due to required auxiliary equipment, permitting and obligatory monitoring.

- **Deposit formation**
  Frequently deposit formation in an engine is attributed to organosilicons or siloxanes, but analysis shows that as much as 30% of the deposits are sulfur. These deposits impact engine function and lead to increased downtime for engine repair.

- **Inhibits siloxane removal media**
  If siloxane removal is required, the hydrogen sulfide concentration must be less than 20ppm to ensure optimum siloxane media life.

- **Odors**
  Even low levels of hydrogen sulfide attribute to site odors.
Safety
Hydrogen sulfide can cause severe health problems in levels over 10ppm. At the levels present in biogas, death can instantly occur from exposure.

Siloxanes also contribute to a number of problems when heated:

- Silicon dioxide formation
  When siloxanes are heated they form silicon dioxide (SiO₂), which is a glass or sand like material. The silicon dioxide deposits are abrasive and form a coating on engine equipment such as the spark plugs, pistons, cylinder heads, and engine valves. When the engine is turned off and cools, the deposits flake off and accumulate in the engine parts, preventing the equipment from functioning as designed. An analysis of the deposits has found that they are more than 40% silicon.

- Electrical Insulator
  Deposits collect near the spark plugs producing an insulating effect, increasing the required voltage and accelerating wear.

- Overheating
  The formation of a coating along sensitive motor parts leads to overheating.

- Emissions
  The presence of siloxanes in the engine also increases the emissions of carbon monoxide (CO) or nitrogen oxides (NOₓ), by inhibiting complete combustion.

- Combustion catalyst
  Siloxanes foul the catalysts used to prevent NOx and SOx formation, which stop the engine from meeting its air emission standards. These catalysts are expensive to replace.

Discussion

Balance between Biogas Conditioning and Engine Maintenance

Given the extensive issues that both hydrogen sulfide and siloxanes can cause to engines and equipment, it is important to consider removing these compounds rather than dealing with the increased maintenance required due to the damage they cause.

Hydrogen sulfide can be removed from biogas using scavenger medias such as iron sponge or SulfaTreat, liquid scrubbing using water or amines, or biologically. Scavenger media such as iron sponge have been used in the natural gas industry for more than 50 years. Both iron sponge and SulfaTreat use iron oxide based media to react with the H₂S in the gas. Depending on the levels of hydrogen sulfide in the biogas, replacement may be required as frequently as once per month. Water or chemical scrubbing strips the H₂S from the gas into the liquid phase. These systems require large quantities of liquids often resulting in high operating expenses.

Biological systems have been removing hydrogen sulfide from air streams at wastewater treatment plants for many years as an odor control solution and are a proven technology. The biotrickling technology has been adapted to handle the higher H₂S concentrations in biogas.

Siloxanes are removed from biogas through an adsorption process using media such as activated carbon, silica gel or polymorphous graphite. These systems typically include two vessels in a lead lag configuration and can be designed as a regenerative or non-regenerative system. In a non regenerative system, the spent media is replaced periodically. In a regenerative system, the media is regenerated periodically by passing a hot air or gas stream through the bed to strip the siloxanes from the bed. This contaminated stream is then flared.
Biogas conditioning does require more equipment, increasing capital costs. However, the overall annual savings generated from reduced operation and maintenance costs on the engine results in a payback period of between 2 and 5 years.

Removing the hydrogen sulfide and siloxanes from the biogas significantly reduce the maintenance requirements created by these contaminants. Table 2 summarizes the potential savings resulting from conditioning the gas prior to burning it in an engine.

**Table 2: Annual Savings resulting from Biogas Conditioning before Utilization of the Biogas in an Engine**

<table>
<thead>
<tr>
<th>Issue</th>
<th>Annual Savings</th>
<th>Change in Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spark plug replacement</td>
<td>$2,000 – $50,000</td>
<td>Reduces frequency of changes by 3 – 5 times</td>
</tr>
<tr>
<td>Oil changes</td>
<td>$10,000 – $60,000</td>
<td>Adds 500 – 3,500 hours</td>
</tr>
<tr>
<td>Engine maintenance</td>
<td>$75,000 – $100,000</td>
<td>Increases availability by 3 – 5 times</td>
</tr>
</tbody>
</table>

Operation and maintenance savings is not the only area of savings when an engine is running smoothly on biogas; if the biogas engine is down for maintenance, the wastewater treatment plant will have to utilize power from the grid; power which it pays for. By having a biogas engine with high availability, the plant will maximize its savings through the use of its biogas.

**Case Study**

Consideration of a typical wastewater treatment plant biogas stream will be considered to demonstrate the savings of installing conditioning equipment. A 250scfm biogas stream, with concentrations of hydrogen sulfide and siloxanes at 1,000ppm and 100ppm, respectively, produces approximately 1MW of electricity.

After installation of a biogas conditioning system to remove both hydrogen sulfide and siloxanes, operation and maintenance costs dropped significantly. Over the years, the plant experienced an average annual savings of $18,000 due to reduced oil changes, $5,000 from less frequent spark plug changes, and approximately $75,000 as the engine itself required considerably less maintenance. The average total annual savings were $98,000.

Prior to the installation of biogas conditioning equipment, the engine was down for maintenance approximately 15% of the time. During this time, approximately $105,000 worth of electricity was purchased from the power authority for the plant. By increasing engine availability, less electricity was required from the grid, resulting in operating savings.

The total biogas conditioning equipment cost was $500,000. Removal of the H₂S using a biological system cost approximately $150,000. Removal of the moisture and siloxanes costs approximately $350,000. The hydrogen sulfide system requires $1,000 of nutrients annually. The siloxanes removal system has regenerable media that requires replacement once per year at a cost of $2,500.

The payback period for the installation of gas conditioning equipment was 2.5 years for this situation. As hydrogen sulfide and siloxane concentrations increase, the savings are more predominant and the payback period will decrease.

**Conclusions**

Biogas conditioning removes the hydrogen sulfide and siloxanes from the biogas stream to allow it to be burned in an engine with minimal detrimental effects. The significant reduction in operation and maintenance costs on the engine allow the engine to have a higher availability rating and maximum
electricity generation. Although the savings in operation and maintenance are significant enough to promote biogas conditioning, the prevention of engine downtime is the main reason for installation of a biogas conditioning system.

**BIBLIOGRAPHY**
