Benefits of Digester Gas Scrubbing at the Dayton WWTP

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Overview

• Composition of Digester Gas
• Undesirable Components and Effects
• Gas Scrubbing Technologies
• Case Study at Dayton WWTP
Digester Gas

- Gas produced during reduction of organic matter under anaerobic conditions in the Anaerobic Digesters.
- Composed primarily of methane and carbon dioxide.
- Fuel (heat) value of digester gas is typically 550 to 650 BTU/CF.
- Contains lesser quantities of other gases such as hydrogen sulfide, nitrogen, water vapor, and volatile organic compounds (mostly siloxanes).
Composition of Digester Gas

- Methane, CH$_4$: 60 – 65%
- Carbon dioxide, CO$_2$: 35 – 40%
- Water Vapor, H$_2$O: 1 – 6%
- Nitrogen, N$_2$: <1%
- Hydrogen sulfide, H$_2$S: 100 to 3,000 ppm
- Siloxanes: 100 to 10,000 ppb

Heat value of methane is approximately 1,000 BTU/CF
Undesirable Digester Gas Components

- Hydrogen Sulfide
  - Siloxanes
- Particulates
- Water Vapor
- Carbon Dioxide
  - Nitrogen
Hydrogen Sulfide and Effects

- Hydrogen Sulfide ($H_2S$) gas when combined with water vapor produces a weak acid:
  
  \[ \text{hydrosulfuric acid: } H_2S \text{ (aq)} \]

- Corrosive to metals
  - Combustion chamber
  - Intake and exhaust piping

- Produces sulfur compounds during combustion

- Target concentration in feed gas: <100 ppm
Siloxanes – what are they?

- The word *siloxane* is derived from the words *silicon*, *oxygen*, and *alkane*.
- They belong to the wider class of organo-silicon volatile organic compounds (VOCs).
- Siloxanes can be found in products such as cosmetics, deodorants, defoamers, toothpaste, water repelling windshield coatings, lubricants, food additives, and soaps.
Siloxane species

Typical species analyzed for are D3, D4, D5, D6, and total siloxanes.

Recommended total siloxane concentrations:

- Reciprocating engines and boilers <100 ppb
- Turbines / Microturbines < 50 ppb
Effect of Siloxanes

- Siloxanes degrade to silicates ($\text{SiO}_2$ & $\text{SiO}_3$) at high temperature and create impermeable glass particles. These particles bond onto hot metal surfaces.

- Reciprocating piston engines – forms deposits and hot spots in the combustion chamber, valves, valve seats, piston crowns and cylinder walls.

Siloxane damage to upper cylinder area and piston
Effect of Siloxanes

- Boilers – deposits a coating of silicate on boiler tubes that lowers heat transfer efficiency.
- Gas turbines – deposits on turbine blades leading to blade erosion and a significant drop in operating efficiency.

Clean boiler tubes

Siloxane deposits on tubes
Other Gas Component Effects

- **Particulates**
  - Form deposits on engine surfaces and boiler equipment
  - Impact / deposit on turbine blades

- **Carbon Dioxide**
  - Inert gas, lowers heat value of digester gas

- **Water Vapor**
  - “Wet” gas forms acids - corrosive to machinery
  - Lowers heat value
• **Definition** – Process of removing one or more undesirable components from a gas stream.
  • Typically targeted at removing hydrogen sulfide (H$_2$S), siloxanes, and particulates.
  • Optional removal of carbon dioxide and water vapor for specific applications.
Reasons for Gas Scrubbing

- Decrease engine maintenance intervals
- Improve fuel (heat) value
- Improve engine performance – more power!
- Sell gas to utility (pipeline quality)
- Produce compressed natural gas (CNG) for City fleet use
- Happier maintenance staff!
Gas Scrubbing Technologies

- Conventional Unit Processes
  - Adsorption (Dry Scrubbing)
  - Wet Scrubbing
  - Refrigeration (a.k.a. Chilling, Dehydration)

- Pressure Swing Adsorption (PSA)

- Other less common methods
  - Cryogenic Separation
  - Membrane Separation
## Gas Scrubbing Technologies

- **Relative Cost, Yield, and Purity of Various Methods**

<table>
<thead>
<tr>
<th>Technique</th>
<th>Cost per CCF to perform ($)</th>
<th>Yield %</th>
<th>Purity %</th>
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<tbody>
<tr>
<td>Chemical Absorption</td>
<td>$1.09</td>
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<td>98</td>
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<tr>
<td>High Pressure Water Scrubbing</td>
<td>$0.59</td>
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<tr>
<td>Cryogenic separation</td>
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<td>Membrane separation</td>
<td>$0.86</td>
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</tbody>
</table>

Eindhoven University of Technology, July 3, 2008
(cost converted at €1 = $1.38)
Chemical Adsorption (Dry Scrubbing)

- Passing gas through adsorption media such as activated carbon, activated alumina, iron sponge, or synthetic resins.
  - Component is adsorbed onto media.
  - Media is either exhausted and replaced or regenerated

- Examples:
  - Iron sponge (iron oxide on wood chips) for removing $\text{H}_2\text{S}$
  - Proprietary adsorbents, e.g. Sulfa-Treat, for $\text{H}_2\text{S}$
  - Activated carbon or activated alumina for siloxane removal
Wet Scrubbing

- A method of passing the gas through water or another liquid medium for the purpose of removing particulates or other gases.

Usage
- CO₂ removal – carbon dioxide is soluble in water.
- Particulate removal
- H₂S removal
Wet Scrubbing

• High-pressure wet scrubbing is the most frequently used method of CO₂ removal at WWTPs.

• Requires inlet gas pressure to be raised to 150 psi to 300 psi to increase CO₂ solubility.

• H₂S is usually removed upstream to avoid compressor corrosion.

• Process can achieve 98% methane.
Refrigeration (Chilling, Dehydration)

- Mechanical refrigeration that removes moisture by lowering the temperature of the gas to condense the water vapor. Other impurities also removed in condensate.

- Removes:
  - Moisture - dewpoint < 40°F
  - 90 - 100% particulates
  - 70 - 80% siloxanes
  - 20 - 30% H₂S
Conventional gas scrubbing uses a series of unit processes selected to meet the fuel requirements of the end use.

**Net Yield:** 75% – 92%
Pressure Swing Adsorption (PSA)

- A mechanical pressure switching system that rapidly cycles from adsorption to regeneration.
- Regeneration is desorption of the adsorbed material under vacuum conditions.
- Uses molecular sieve media and other medias to allow the passage of methane but adsorb CO$_2$, H$_2$S, and siloxanes.
Molecular Sieve Media

- Specialized media that traps smaller \( \text{CO}_2 \) and \( \text{N}_2 \) molecules while allowing methane to pass through media.
- Media is capable of rapid adsorption and desorption cycles.

Molecular Sieve Media – Pore Size at 3.7 Angstroms

Angstrom – length equal to \( 1 \times 10^{-10} \) meter
PSA Cycle Diagram

Pressure Phase – Adsorb

- Vessel is pressurized
- Feed gas flows upward thru media bed
- Target compounds adsorbed while methane passes thru the bed
- Over time the bed will become saturated

Vacuum Phase – Regen and Purge

- Vacuum applied to bottom of adsorbent bed
- De-adsorbed compounds extracted as “Tail Gas”
- Methane purge gas applied from top
Typical PSA Flow Diagram

PSA gas scrubbing performs multiple chemical adsorptions in a single step.

PSA System
(4 stages of process for continuous flow.)

Product Gas
(98% Methane)

Methane Yield:
80% - 91%

Tail Gas
(22% Methane)

Vacuum Pump
Dayton, Advanced Wastewater Treatment Facilities (AWTF) located at 2800 Guthrie Road, Dayton, OH.

Rated at 72 MGD and peak 180 MGD

Secondary (nitrification) plant with effluent filters and diffused post aeration

Four 85-ft and four 90-ft diameter Anaerobic Digesters (1.2 & 1.6 MG)

52-ft diameter Gas Holding Sphere (300,000 CF at 50 psi)

800,000 CF/day gas generation

Energy recovery facilities

Additional information [http://water.cityofdayton.org/Water/wwtp_main.asp](http://water.cityofdayton.org/Water/wwtp_main.asp)
Gas Utilizing Equipment

• Co-generation Engines
  • 3 Waukesha Engines
  • Dual fuel: Digester Gas and Natural Gas.
  • “Lean burn” engines
  • 720 kW each on digester gas
  • 900 kW each on NG or high-BTU (scrubbed) gas
• Present Strategy:
  • Peak-shave energy usage during high flow periods
Gas Utilizing Equipment

- Boilers
  - 3 HURST Hot water boilers
  - 350 Horse Power
  - Design: 3-Pass Wet-Back
  - Burner Capacity: 14.7 Million BTU/Hour
  - Hot water Temperature: 180 °F
Selection Process

- Found that refrigerated gas drying (chiller) was best method at time. Added chiller in 1995.
- Siloxane was not removed adequately and high maintenance intervals continued on engines.
- Learned about proprietary molecular sieve technology from Guild Associates (Dublin, OH) in 2009.
- Selected PSA for implementation at WWTP.
PSA Gas Scrubber Specifications

- Designed Capacity: 1,000,000 SCFD
- Product gas
  - 524,000 SCFD
  - Methane: > 98%
  - CO₂: < 2%
  - Methane Yield: 85.6%
- Tail Gas
  - 476,000 SCFD
  - Methane: 22%

<table>
<thead>
<tr>
<th>Biogas Feed Properties</th>
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<tr>
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<td>Pressure, psig</td>
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<td>CO₂</td>
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<tr>
<td>H₂S</td>
</tr>
<tr>
<td>Siloxanes</td>
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<tr>
<td>H₂O</td>
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<tr>
<td>HHV BTU/FT³</td>
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Improved Digester Gas Schematic

- **Anaerobic Digesters (700,000 SCFD)**
- **Waste Gas Burners**
- **Tail Gas Burner**

**Diagram Details:**
- **COGEN Engines:** 720 KW each on DG, 900 KW each on NG
- **Boilers**
- **Compressors**
- **Gas Sphere (50 PSI)**
- **PSA Gas Scrubber**
- **Chiller**
- **Productos Gas (98% Methane)**
- **Future to Utility, CNG (98% Methane)**

**Legend:**
- **Valve**
- **Ex. DG Piping**
- **PSA Feed Piping**
- **PSA Clean Gas**
- **Clean Gas, Ex Piping**
- **Tail Gas Piping**
Location of PSA Gas Scrubber

Location of PSA Gas Scrubber next to Co-generation Building
Major Components of PSA Gas Scrubber

- **Feed Compressor**
  - Type: Reciprocating
  - Capacity: 1 Million SCFD
  - 60 HP Motor
  - Compresses from 40-50 to 105 PSIG

- **Vacuum Compressor**
  - Type: Liquid Ring
  - Capacity: 0.5 Million SCFD
  - 150 HP Motor
  - Reduces from 3 in to 18 out PSIA
Major Components of PSA Gas Scrubber

- 4 Adsorber Vessels that sequence these functions:
  - Pressurizing
  - On-line (adsorbing)
  - De-pressurizing
  - Purging

- 4 Buffer Tanks
  - Two Equalization
  - Two Repressurization

- Tail Gas Buffer Tank
- Purge Tank
This slide shows:

- Connection to the tail gas burner from tail gas buffer tank.
- Connection of clean gas to the tail gas burner in case we cannot use the clean gas.
PSA Gas Scrubber

- This slide shows:
  - Digester gas insulated piping to the PSA from Co-generation building Chiller.
  - Clean gas red piping to the Boiler and Co-generation Engines.
Tail Gas Flare

- **Tail Gas Burning obstacles:**
  - Getting a new air permit from Regional Air Pollution Control Authority (RAPCA)
  - Existing flare would not work due to high (30%) methane requirement
  - Lead time on customized flare
  - Zeeco, Inc. designed lean burning flare tip for 22% methane combustibility
Advantages of PSA Scrubbing

- Lowers maintenance of engine equipment
- Single process versus multiple unit processes
- No consumables and PSA media has 5+ year life
- Lower O&M cost than conventional processes
- Less liquid discharge (compared to wet scrubbing for CO2 removal)
Scrubber Start-up

• Engine-Generator startup issues
  • Connect to the Natural Gas Line
  • Adjusted air/fuel ratio for the engines
  • Had to retune engines

• Boiler startup issues
  • Adjusted air/fuel ratio on two boilers
Cost of the project

- PSA system cost $1.9M installed.
- Received American Recovery and Reinvestment Act (ARRA) grant money for the project.
- Pay back period will be between 5-10 years due to:
  - Reduction in maintenance cost of the engines and boilers.
  - Higher engine and boiler efficiency
  - Future plan to sell to local gas utility, or build a CNG station for City vehicles.
Questions
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