A "Powered Up" Anaerobic Digester

Lessons Learned in Energy Optimization

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Proposed Agenda

- Background
- Goals - "Net" Gain
  - Energy: Optimize production
  - Energy: Minimize parasitic demands
  - Financial: Minimize capital and operating expense
- Historic Lessons Learned – Do’s & Don’ts
- Project Approach
- Questions and Discussion
Background – *High Rate Digestion*

- **Anaerobic Digestion for Biogas**
  - Mesophillic 37-41C
  - Thermophillic 50-60C

- **Biogas Production**
  - 12 to 18 std CF/dry lb Volatile Solids
  - VS reduction 45 to 65% typical
  - **16 to 24** std CF/dry lb Food Waste (COD)
Effects of Reaction Rate

Old Perth Gas Mixing System

= low mixing efficiency
Effects of Reaction Rate

Strong Mixing System, Operated Intermittently
  = much improved efficiency

Pumped Mixing = super efficiency, rxn rate
### TYPICAL COMPOSITION

<table>
<thead>
<tr>
<th>Component</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane, CH$_4$</td>
<td>50–75%</td>
</tr>
<tr>
<td>Carbon dioxide, CO$_2$</td>
<td>25–50%</td>
</tr>
<tr>
<td>Water vapor, H$_2$O</td>
<td>5–15%</td>
</tr>
<tr>
<td>Nitrogen, N$_2$</td>
<td>0–10%</td>
</tr>
<tr>
<td>Hydrogen, H$_2$</td>
<td>0–1%</td>
</tr>
<tr>
<td>Hydrogen sulfide, H$_2$S</td>
<td>0–3%</td>
</tr>
<tr>
<td>Oxygen, O$_2$</td>
<td>0–2%</td>
</tr>
</tbody>
</table>

*Siloxanes*
## Table ES-1. Energy Benefit Comparison of Anaerobically Digested Food Waste and Anaerobically Digested Municipal Wastewater Solids.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Food Waste 15-day MCRT AVG (Range)</th>
<th>Food Waste 10-day MCRT AVG (Range)</th>
<th>Municipal Wastewater Solids 15-day MCRT AVG (Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane Production Rate</td>
<td>ft³/dry ton applied(1)</td>
<td>13,300 (9,800 – 17,000)</td>
<td>9,500 (6,600 – 14,400)</td>
<td>10,000 (7,500 – 12,600)</td>
</tr>
<tr>
<td></td>
<td>ft³/wet ton delivered(2)</td>
<td>3,300 (2,500 – 4,300)</td>
<td>2,400 (1,700 – 3,600)</td>
<td>NA(6)</td>
</tr>
<tr>
<td></td>
<td>m³/dry metric ton applied(1)</td>
<td>420 (300 – 530)</td>
<td>300 (200 – 450)</td>
<td>310 (230 – 390)</td>
</tr>
<tr>
<td></td>
<td>m³/wet metric ton delivered(2)</td>
<td>100 (75 – 135)</td>
<td>75 (50 – 110)</td>
<td>NA(6)</td>
</tr>
<tr>
<td></td>
<td>ft³ per day/1,000 ft³ digester volume</td>
<td>2,300 (1,100 – 3,200)</td>
<td>2,600 (1,800 – 3,800)</td>
<td>750 (550 – 930)</td>
</tr>
<tr>
<td>Electricity Production Rate(3)</td>
<td>kWh/dry ton applied(1)</td>
<td>990 (730 – 1,300)</td>
<td>710 (490 – 1,080)</td>
<td>750 (560 – 940)</td>
</tr>
<tr>
<td></td>
<td>kWh/wet ton delivered(2)</td>
<td>250 (190 – 320)</td>
<td>180 (130 – 270)</td>
<td>NA(6)</td>
</tr>
<tr>
<td></td>
<td>kWh/dry metric ton applied(1)</td>
<td>1,100 (800 – 1,400)</td>
<td>780 (540 – 1,190)</td>
<td>830 (620 – 1,040)</td>
</tr>
<tr>
<td></td>
<td>kWh/wet metric ton delivered(2)</td>
<td>280 (200 – 350)</td>
<td>200 (140 – 300)</td>
<td>NA(6)</td>
</tr>
<tr>
<td></td>
<td>kWh per year/ 1,000 ft³ digester volume</td>
<td>43,700</td>
<td>57,000</td>
<td>14,600</td>
</tr>
</tbody>
</table>

### Source:
Value of Biogas Energy

- Biogas Value ... Has Dropped!
  - “As Is” 600 BTU/cf
  - 60-65% of Nat.Gas BTU/cf
  - Cleaned to commercial standards?
    - BTU value is too low for ROI
Goals for Anaerobic Digestion

- Stabilize the biosolids
  - Pathogen reduction
  - VS destruction
- Minimize capital expense
- Optimize the process
- Maximize “net” energy
  - Increased biogas production
  - Minimize parasitic demands
  - Optimize energy input for target energy production
A Plan: Specific to Utility Size & Needs
Threshold Size: 0.5 to 5 MGD? Above 5 MGD?

Project Considerations – For Your Utility:
- Onsite use of natural gas reduced (winter)
- Proximity to a user of natural gas?
  - Locate the digester near large user, or
  - Locate digester near private pipeline
- Onsite use of electrical power; baseline load
- Solids separations and control ammonia loading to POTW
  - Goals: reduce land application costs

Consider also: the value of the products
- Biogas
- Electricity
Finance: Develop a Business Plan

Value of Biogas as Product

- 0.5 to 5 MGD?
- Above 5 MGD?

Natural Gas Production Economic Analysis

- Capital investment = ?
- Pick a reasonable payback at $4/MBTU Nymex
- Recommendations Based on Economic Analysis
- Estimate/Verify:
  - Generating more methane than required
  - Methane production can be optimized
  - Value of biogas produced (10 to 20 year projection)
  - Are there suitable customers available for sale of biogas i.e. directly to large nondomestic user
Finance: Control Capital Expense

Minimize Un-necessary Capital investment

- Expensive tankage
- Large Tanks
- Extensive gas cleanup
- Expensive piping
- Gas storage/compression
Figure 1: Relative magnitude of the different fuel sources used to heat the boiler. The dashed lines represent the energy that can be utilized from theoretical maximum amount of biogas generated. The solid black line is the total amount of energy required to heat the boiler.
Finance: Optimize Digester Biogas Production

Biogas Produced Before and After Digester Improvements Compared to Theoretical Biogas Generation

Operating Month

0  50  100  150  200  250  300
Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec

Problem solved re Biogas Metering

Grease entrainment

Avg CCF/d thru 2007  Avg CCF/d 2008  Theoretical (low)  Theoretical (high)
Avg CCF/day 2009  Avg CCF/day 2010  Avg CC/day 2011  Avg CCF/day 2012
FINANCIAL DRIVERS

1. Food Processors within target radius
   - Surcharge revenue
   - Energy value

2. Grease - Commercial & Residential Sources
   - Surcharge revenue
   - Energy value

3. Industrial/Concentrated Loads
   - Target: COD 10,000 mg/L or greater

NOT RECOMMENDED

Agricultural – Manure
   - Not recommended ... low digestable VS/lb

Septage
   - Not recommended... low digestable VS/lb
Energy: Optimize Production

Variables

- **Mixing**  (not Perth gas mixing)
- Grease entrainment
- Feed rate & timing
- Add’l Industrial feed(s)
Energy: Minimize Parasitic Demands

Necessary
- Minimal mixing
- Heating to 90F ... 85F?
- Biogas moisture removal

Not Necessary
- 50% or more mixing “on” time
- Over-sized mix flow/under-sized piping
- Heating to 95-98F
- Extensive gas cleanup
- Long SRT HRT/higher mixing energy
- Supplemental natural gas for digester boilers
Capture Biogas Value as Heat

- 0.5 to 5 MGD  ✔️
- Above 5 MGD  ✔️
  (beyond baseline digester heating demands)

- Onsite Facilities: hot water heating
- Nearby Facilities: hot water heating

- Efficiency: 75-85%
Biogas to Heat
Biogas to Heat

- Use the right boiler! AND the right heat exchanger!
- Avoid boilers that need natural gas supplement to maintain sufficient BTU value
- Use biogas conditioning equipment
- Use the right heat exchange equip.
Biogas as Power - Electric

- 0.5 to 5 MGD
- Above 5 MGD \(\surd\) (beyond baseline digester heating demands)
- Onsite Facilities: existing motor loads
- Nearby Facilities: not economical (yet)
- Efficiency: 30-35% thus long payback periods!
Biogas as Power - CHP

- 0.5 to 5 MGD
- Above 5 MGD

Combined Heat & Power CHP

where
- Existing motor loads are powered FIRST
- Waste Heat - used for baseline digester heating

- Efficiency: 70-85%
$3M to $4M/MWe installed

- Internal Combustion (most common):
  - Gas cleanup 1) moisture  2) *maybe* H2S and siloxanes
  - Higher risk approach: reduced cleanup, more frequent engine rebuilds
  - Typical size range: 65KWe to 1MWe

*Your Fuel is “Free”!*
CHP Gen. Sets & Gas Clean Up

- External Combustion (R&D phase)
  - Gas cleanup 1) moisture removal
  - Maintenance: less rebuilds
  - Size 43-60KWe: No large units available
Example budgetary pricing

6 MGD WWTP Digester CHP

INTERNAL COMBUSTION GEN. SET (0.1-0.12MWe) $0.55M + $0.15M install’n
- H2S Removal System (Optional) .................................................................$96,406.00
- Moisture Removal/Compression System (Required) ...............................$187,338.00
- Siloxane Removal System (Optional) ......................................................$68,252.00
- ENI Ipower 65 (2 Required) .................................................................$95,804.00/ea
- *Each unit requires 22 scfm Biogas Fuel Flow @ 60% CH4

CAPSTONE TURBINE EQUIPMENT (0.1 MWe) $0.575M + $0.2M install’n
- H2S Removal System (Optional) .................................................................$96,406.00
- Moisture Removal/Compression System (required) ...............................$230,449.00
- Siloxane Removal System (required) ......................................................$35,083.00
- Capstone CR65-ICHP (2 required) .........................................................$105,355.00/ea
- *Each unit requires 23scfm Biogas Fuel Flow @ 60% CH4

Equipment Prices do not include:
1. A control panel or chiller for use in a classified area
2. Field/installation work
Goals

- There is no money to waste...
  *Protect the Sewer Fund* and thus the POTW

- Reliability

- Maximum *Net Energy Production*

- Mitigate *Historic* Lessons Learned:
  - Hairballs and grease mats
  - Foam, acid attack, and boiler “snuff out”
  - Over-mixing
  - Fouling of piping, Hx, pumps
Lessons Learned (30 minute version)

**DO’S**
- Optimized mixing
- Good feedstocks
- Redundant facilities
- Use existing facilities
- Use the right boiler
- Install scum-buster & foam-buster equip.
- Headworks FineScr.
- Make Money!

**DON’TS**
- Under-mix or over-mix
- Dilute waste streams
- Feed manure (low VS & COD)
- Expensive rehab/upgrades
- Use the wrong boiler
- Allow scum accumulation
- Ignore condensate
- Digest septage (more)
Lessons Learned

Foaming
A Few Conclusions

BIOGAS is a Super Source of Sustainable Energy

→ *Planning is key for cost effective use & benefits*

- Avoid “greenwashing” schemes ... Biogas Projects *Can Make Financial Sense*
  - *Biogas-to-Heat  Biogas-to-CHP ... Both Make Sense, Right-Sized*
- Biogas Clean-up is a key consideration & cost ... don’t miss it
- Operation, Maintenance & Replacement
  - *key considerations for design*
- Identify & Achieve Payback Goals
- **Utilize Project Grants and Subsidies**
Project Approach

- Business Plan First; Then Utilize Project Grants and Subsidies

- F&V has been successful at helping our clients take advantage of subsidized Project Funding which offers 50% principal forgiveness (like a grant)

- A few examples:

  Plainwell WRP Improvements – Modifications to existing anaerobic digester to receive high strength waste streams to boost biogas production

  West Bay County – High strength from commercial Allendale WWTP Anaerobic Digesters