EVALUATION OF ENERGY RECOVERY OPTIONS FOR CONVERSION OF AEROBIC DIGESTERS TO ANAEROBIC DIGESTION

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ABSTRACT. The ‘threshold’ facility size for implementing anaerobic digestion has been debated and is dependent on several factors including process considerations. By utilizing the model developed for this case study, it is possible to determine the appropriate scale for conversion from aerobic to anaerobic digestion for certain facilities.

This paper will discuss a case study in Florida for evaluating the conversion of an existing aerobic digestion system to anaerobic digestion with a focus on energy recovery. By including energy recovery, the Hillsborough County, FL can provide a sustainable energy source while saving money over the planning period. The quantities of sludge processed at the County’s Biosolids Management Facility (BMF) are expected to increase to approximately 27 dry tons per day by 2025. At these quantities, the evaluation shows that energy recovery through conversion to anaerobic digestion will result in a beneficial and sustainable project by utilizing digester gas for digester and thermal dryer operations.

The study evaluated various anaerobic digestion options with a focus on energy recovery for use with the BMF’s digestion and heat drying operations. The model included assumptions on volatile suspended solids reduction and energy input for each process option as well as construction costs. As part of the evaluation, the following criteria were evaluated for the digestion process alternatives:

1) Capital and O&M costs
2) Volume reduction based on digestion process (e.g. enhanced digestion)
3) Potential for gas production and energy recovery
4) Risk factors such as foaming and struvite formation potential
5) Impact on existing operations such as thickening, dewatering, drying, etc…

By implementing the recommended energy recovery alternative, the County will realize the following benefits:

- Better stabilization of the biosolids
- Less drying required due to reduction of biosolids mass
- Reduced natural gas use due to gas recovery and fuel supplementation
- Reduced electrical power consumption due to the elimination of the large aeration requirements
- Carbon footprint reduction
- Continued production of high quality pellet for marketing

KEYWORDS: Anaerobic digestion, biogas, combined heat and power (CHP), gas recovery, energy recovery.

INTRODUCTION

This paper will discuss a case study in Florida for evaluating the conversion of an aerobic digestion system to anaerobic digestion with a focus on energy recovery. The ‘threshold’ facility size for implementing anaerobic digestion has been debated and is dependent on several factors including process considerations. By utilizing a cost model developed for the baseline project, the economic viability of various sized projects can be examined. The benefits of implementing a biosolids energy recovery project are dependant on several factors including facility size, sludge composition, digestion process selection, and energy recovery method.

The Hillsborough County Digester System Improvements Evaluation was completed in May of 2009. The study presented a review of the County’s existing Biosolids Management Facility (BMF) aerobic digester operations. The County’s BMF is a centralized sludge processing facility that produces Class A Biosolids. Dewatered biosolids from the County’s South/Central Region are contract hauled to the BMF, while liquid sludge is pumped from the Northwest Region’s plants directly to the BMF. It should be noted that there is no sludge stabilization provided for the biosolids prior to pumping from the wastewater treatment plants to the BMF. Table 1 summarizes the type of sludge and delivery method for each plant:
Table 1 - Wastewater Treatment Plants – Northwest Service Area

<table>
<thead>
<tr>
<th>No.</th>
<th>Plant Name</th>
<th>Type of Sludge</th>
<th>Delivery Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>River Oaks Advanced Wastewater Treatment Plant</td>
<td>Primary and Secondary</td>
<td>Pumped</td>
</tr>
<tr>
<td>2</td>
<td>Dale Mabry Advanced Wastewater Treatment Plant</td>
<td>Secondary</td>
<td>Pumped</td>
</tr>
<tr>
<td>3</td>
<td>Northwest Regional Water Reclamation Facility</td>
<td>Secondary</td>
<td>Pumped</td>
</tr>
<tr>
<td>4</td>
<td>Van Dyke Wastewater Treatment Plant</td>
<td>Secondary</td>
<td>Trucked</td>
</tr>
</tbody>
</table>

Objectives

The objectives of this paper are to present a summary of the evaluation performed for the County and to extrapolate the findings for other treatment plants of various sizes. As part of the County’s evaluation, the existing digestion and solids handling processes were summarized. The primary focus was to determine what steps can be taken to improve the digestion process by converting the exiting aerobic digestion process to anaerobic digestion. Then, utilize the biogas produced by anaerobic digestion for use as a fuel. To evaluate the solids processing and provide feasibility level costs, several items must be examined including:

- Document the historic and current wastewater and sludge quantities, and determine projections for further analyses.
- Determine the viability of gas production through analyzing the volatile suspended solids (VSS) content of the sludge received at the BMF.
- Establish the capacity of the existing digesters based on historic flows and performance.
- Identify reasonable process alternatives and perform an economic analysis.

METHODOLOGY

Existing Digestions Process

The existing wastewater flows for the County’s Northwest Service Area equal about 20 million gallons per day (mgd) for 2009. This wastewater flow rate represents a sludge production of approximately 17 dry tons per day (dtd). As mentioned previously, the liquid sludge is pumped to the BMF and thickened prior to transfer to the aerobic digestion system.

The sludge is partially stabilized in the four aerobic digesters. Each tank is sized at 1.5 million gallons for a total volume of 6 million gallons.

After digestion, the sludge is pumped to centrifuges and dewatered to approximately 18-20% dried solids. The dewatered sludge is then conveyed and pumped to the BMF’s dryer facility where it is dried to approximately 92% dried solids. The fuel source for the two rotary drum direct dryers is natural gas. The final Class A dried pellet product is stored and then transported for beneficial reuse. Because the dryer equipment is totally reliant on purchased natural gas, the study looked at the viability of utilizing biogas for process heating and fuel for drying.

Process Alternatives

Currently, the liquid sludge received at the Hillsborough County Biosolids Management Facility (BMF) is partially stabilized in four aerobic digesters operated in a “draw and fill” mode. To understand the available process technologies, a brief review of anaerobic digestion processes including mesophilic (single stage and two stage high rate processes), thermophilic, temperature phased digestion (TPAD), and enhanced digestion processes was completed.
While each process has its merits and limitations, a straightforward comparison was completed in an effort to select an anaerobic digestion process to conduct a conceptual level economic analysis. The process comparison included the following criteria, which were scored with respect to Hillsborough County’s objectives:

- Project Capital Costs
- Operation and Maintenance Costs
- Volume Reduction
- Potential for Supplemental Gas Production
- Risk Factors (health and safety)
- Complexity of Operation

It is important to note that each facility that could potentially be retrofitted to anaerobic digestion will have its own unique requirements, and the scoring and evaluation of potential process changes will need to consider these. Based on the scoring for this project, and considering the County’s existing facilities, two stage anaerobic digestion (mesophilic) was selected to complete the economic analysis.

Table 2 presents some of the advantages and disadvantages for the selected process modifications:

<table>
<thead>
<tr>
<th>Alternative Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Two-stage Mesophilic Anaerobic Digestion | ✓ No aeration blowers required compared with aerobic digestion  
✓ Gas generated can be used as an alternative energy source; heating, power production, supplemental gas for dryer system  
✓ Substantial savings on energy costs and lower operations costs  
✓ Greater VSS destruction reduces natural gas capacity requirement of the downstream process units | ✓ Initial capital costs are high  
✓ Must improve GBT performance to thicken sludge up to 5–6% solids  
✓ Very sensitive to the adverse effects of lower temperatures  
✓ Increased potential of odors and corrosive gas production  
✓ New process – will require staff training  
✓ High foaming potential  
✓ Potential for struvite formation (dependant on bio-P removal) |

Once the anaerobic digestion process was selected, capital and O&M costs were developed using a spreadsheet model. This evaluation of the County’s BMF provided the ‘baseline’ project, which is represents an approximate wastewater flow of 20 mgd.

In an attempt to focus on the feasibility of anaerobic digestion with gas recovery, the study made the following general assumptions:

- Conversion from existing aerobic digestion to anaerobic digestion (two-stage mesophilic process).
- Utilize existing digestion tanks for conversion to anaerobic process.
- Existing tank volume is adequate for 20+ days SRT.

The recommended modifications for the County’s sludge digestion process as well as the respective design criteria are discussed below. In addition, conceptual level costs for capital and O&M are presented as annual costs for comparison.
Baseline Project Definition - Two-stage Mesophilic Anaerobic Digestion

Information from the County’s Digester System Improvements Evaluation project was used as the baseline project for estimating the capital and O&M costs, as well as potential gas production and revenues. Information and data gathered for this report was extrapolated for a range of facility sizes using the cost model developed for the baseline project. The various components that are required for conversion from aerobic to anaerobic process (two-stage mesophilic process) are outlined below. The County’s BMF receives sludge from four WWTFs, which represents a wastewater flow of approximately 20 million gallons per day.

For this project, it is assumed that the existing aerobic digestion process would be changed to an anaerobic process by modifying three of the four existing digester tanks. The modifications would include rehabilitation of the existing tanks to include additional piping and gas draw-off connections, mixing systems, yard piping modifications, as well as other items. To meet stabilization requirements, two process tanks are required with a third tank used for storage and flexibility in a “fill and spill” configuration. The process hydraulic retention time (HRT) required for this alternative is used for stabilization and gas production. The gas produced by the system could be used for heating the proposed anaerobic digestion system, and potentially supplementing the existing heat drying process.

The conceptual level design criteria are presented below for the baseline project:

CONCEPTUAL LEVEL DESIGN CRITERIA

- Thickened Sludge Flow: approximately 121,000 gpd
- Design Thickening Requirements: 5.5 %
- Solids Retention Time/Process Configuration with two tanks + one storage:
  - First Stage = 26 days
  - Secondary Digester 2 - 4 days
- VSS destruction: 30-50% (varied for economic evaluation)
- Sludge Average Temperature: 70°F
- Treatment Process Temperature: Mesophilic (85 to 100°F)
- Heat exchanger heat transfer coefficient: 0.9 to 1.6 KJ/m2
- Mixing pumps: 0.025-.04 hp/1,000 gal of digester volume
- Mixing Pumps per tank: 2 pumps
- Turnover Time of tank contents: 20-30 min
- Velocity Gradient (G): 50-80 S-1

The process and equipment changes described below are required for conversion from aerobic to anaerobic digestion for the baseline project developed for the County. However, the overall requirements for a digestion process change at a typical aerobic digester facility would be similar and may include, but not be limited to, the following:

PROCESS/EQUIPMENT CHANGES

Area 1 - Sludge Holding Tanks
- Sludge holding tanks structural rehabilitation – repairs.
- Replacement of the sludge holding tanks aeration blowers - same capacity.

Area 2 - Sludge Pumping and Thickening
- Replace/rehabilitate sludge thickener feed pumps.
Area 3 - Sludge Digester

Modify three existing aerobic digesters to anaerobic digesters. Two process tanks and one storage tank for operational flexibility. Modifications to tanks will include: gas collection piping, vacuum relief valves, and flame traps.

Overflow piping from primary/process digesters to secondary digester.

New pump mixing system for three tanks (two process tanks and one storage tank). Modifications will include piping to transfer sludge between digester tanks.

Feed piping additions and control valves for sludge feed control and other appurtenances required to control and monitor the process.

Area 4 - Gas and Heating Management Area

Sludge heating equipment including heat exchanger and boiler system. This system would be heated by gas generated by the anaerobic digestion process.

Addition of gas management system including storage, gas treatment, gas monitoring equipment, etc…

Heat exchanger equipment and excess waste heat sink.

Area 5 – Combined Heat and Power (CHP)

Addition of engines for electrical power production and waste heat recovery.

As mentioned previously, Hillsborough County’s BMF includes sludge drying using purchased natural gas as fuel. For this analysis, it is assumed that new CHP systems would utilize the biogas for electricity production and the waste heat would be used for digester heating. For this analysis, CHP is selected based on its reliability and common use. In addition to CHP, direct drive systems are also an alternative for utilizing biogas. Direct drive applications have relatively high efficiencies and include directly using biogas to run the primary mover such as pumps or blowers. While this technology has been used at wastewater treatment plants, it is not evaluated here for the sake of simplicity, and also due to its less than dependable results.

The economic analysis for the ‘baseline’ project includes the following items, considerations, and assumptions:

- Thickening equipment must be added or upgraded.
- Utilization of waste activated sludge (WAS) only.
- Biogas is used by CHP system for electricity production with waste heat used to heat the digestion process.
- Excess heat produced by the CHP system is wasted.
- Digested WAS has a 70% VSS fraction.
- VSS destruction between 30 and 50%.
- Electricity costs, $0.10/kW-hr
- Gas cost, $1.00/therm
- Electrical efficiency, 30% \(^{(1)}\)
- Power to heat ratio, 64% \(^{(1)}\)
- CHP capital cost, $2,000 per kW-hr \(^{(1)}\)
- IC engines maintenance cost, $15/kW-hr/year \(^{(2)}\)
- No land acquisition is required.
- Existing aerobic digester tanks can be renovated for use as anaerobic digesters.
- Yard piping complexity must be examined for each facility.
- Cost for supernatant treatment is included due to its return affect on the liquid treatment process.
- Costs for treatment of concentrated return waste streams is included.

Sources:

(1) EPA CHP Opportunities and Benefits of Combined Heat and Power at Wastewater Treatment Facilities – April 2007
RESULTS AND DISCUSSION

Economic Analysis

The cost model and input data used to determine the costs for the baseline project (approximate 20 mgd treatment plant) were used to develop costs for the 5 mgd and 30 mgd digestion projects. The capital costs were determined by adjusting the equipment sizes (horsepower and capacity) as well as the number of units necessary for the appropriate sized anaerobic digestion facility. Other capital costs for items such as digester modifications and piping were scaled based on the treatment plant sizes and expected sludge volumes.

The operation and maintenance costs were also input for the 5 and 30 mgd treatment plants based on the cost model used for the 20 mgd baseline project. Once again, the input data was scaled based on the required equipment size/capacity, horsepower and equipment runtime for that plant size.

For this evaluation, facility sizes for 5 through 30 mgd were selected in 5 mgd increments to determine the practicality of converting to anaerobic digestion with gas recovery. Using the capital and O&M costs developed in the cost model for the 5, 20 and 30 mgd treatment plants, trend lines were used to estimate the costs for the remaining sized plants (10, 15, and 25 mgd).

Figure 1 presents the estimated capital costs for conversion from aerobic to anaerobic digestion. The estimated capital cost in $ per gallon for the plant sizes show the expected ‘economy of scales’ for the various sized facilities. The approximate costs for the 5 mgd and 30 mgd treatment plants are $1.75 and $0.60 per gallon respectively.
Figure 2 presents the annual O&M costs for anaerobic digestion versus plant size.

Figure 2

Annual O&M Costs vs. Plant Size for Anaerobic Digestion

For anaerobic digestion with gas recovery to be successful, the VSS fraction and VSS percent destruction are critical. For this evaluation, only WAS is assumed to be digested, which is a worst case scenario because it is well known that WAS has a much lower gas production potential than primary sludge. Tables 3 and 4 present the biogas production with resultant energy production and estimated revenues for 30 and 50% VSS destruction.

### Table 3 – Energy/Heat Production and Revenues for 30% VSS Destruction

<table>
<thead>
<tr>
<th>Plant Size (AADF MGD)</th>
<th>Energy potential (BTU/day)</th>
<th>Gas usage for digestion (BTU/day)</th>
<th>Electricity produced using an IC Engine (kW-hr)</th>
<th>Heat recovered from CHP system (BTU/day)</th>
<th>Excess heat available (BTU/day)</th>
<th>Power generation revenue ($)</th>
<th>Heat generation revenue ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>16,077,852</td>
<td>5,144,913</td>
<td>59</td>
<td>10,289,825</td>
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<td>25,724,563</td>
<td>295</td>
<td>51,449,126</td>
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<tr>
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### Table 4 – Energy/Heat Production and Revenues for 50% VSS Destruction

<table>
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<tr>
<th>Plant Size (AADF MGD)</th>
<th>Energy potential (BTU/day)</th>
<th>Gas usage for digestion (BTU)</th>
<th>Electricity produced using an IC Engine (kW-hr)</th>
<th>Heat recovered from CHP system (BTU/day)</th>
<th>Excess heat available (BTU/day)</th>
<th>Power generation revenue ($)</th>
<th>Heat generation revenue ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
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<td>8,574,854</td>
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<td>17,149,709</td>
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</table>

Based on the preliminary estimates for power and heat revenues generated from the recovery of the biogas, it is evident that the VSS fraction in the digested sludge is critical. The straight line increase in revenues from 30% to 50% VSS fractions results in a 67% increase in revenues. It should be noted that additional heat is available and must be wasted if not used. This analysis assumes that much of the excess heat available is wasted and no revenue is recovered, which is typical for Florida. However, there are options available for additional heat recovery, such as chillers, HVAC units, etc… that were not evaluated as part of this study.

Figure 3 presents the revenues expected from CHP systems based on electrical power production and waste heat recovery for 30, 40, and 50% VSS destruction. As expected, the revenues increase substantially for larger plants with greater VSS destruction.
**Figure 4** presents the payback periods expected for the various sized projects for the three VSS destruction percentages. While the preferred short payback periods are not evident, the figure does show that there is a clear economic tipping point for treatment plants of about 12 to 15 mgd and larger based on the assumptions presented herein. This seems to validate the perceived view of treatment plant size for anaerobic digestion. However, the VSS fraction and destruction percentage are critical.

**CONCLUSIONS**

By implementing an anaerobic digestion process the following benefits can be realized:

- Reduced biosolids mass and better stabilization of the biosolids.
- Reduced power costs due to the elimination of the large aeration requirements for aerobic digestion process.
- Reduction in hauling costs, if applicable, due to reduced biosolids mass from anaerobic digestion.
- Utilize sustainable energy source (digester gas) to reduce carbon footprint and offset natural gas and power usage.
Before a digestion process change can be implemented, several items must be evaluated for the specific facility considered for the process change. A preliminary design scope of work should include the following items:

- Confirm sludge VSS fraction for the influent sludge.
- Structurally inspect the existing digester tanks to ensure that they can be retrofitted for use as anaerobic digesters.
- Confirm energy balances and heat transfer efficiencies to validate cost savings due to gas production.
- Determine the best configuration and location of the proposed equipment and facilities including process and electrical.
- Perform evaluation with regards to existing equipment condition and need for replacement.
- Perform economic evaluation for capital and O&M costs to verify the recommended project’s viability.

REFERENCES:

(1) April 2007; EPA CHP Opportunities and Benefits of Combined Heat and Power at Wastewater Treatment Facilities.