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BIOSOLIDS: FERTILIZER OR FUEL?

PART 2: FUEL

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Total System Approach to Maximizing Solids Processing Efficiencies

INTRODUCTION
When designing wastewater solids processes, engineers often tend to focus on individual processes rather than take a more holistic approach that optimizes the total system. Increasingly, one of the main goals of wastewater treatment facilities is to achieve energy neutrality; that is, to minimize costs and environmental consequences associated with purchased energy. To make the energy efficiency equation favorable, designers have to focus on increasing the potential for pairing solids processes and exploiting their operational synergies.

Over the past several decades, anaerobic digestion has been the mainstay of solids treatment with approximately 60 to 70% of treatment facilities around the world using the technology for solids stabilization. The process reduces the amount of solids for downstream processing, beneficial use, or disposal. The odor potential of the treated biosolids is greatly reduced by reduction of organic matter in the digesters. Low rate anaerobic digestion can operate without mixing energy input. High rate digestion systems are more economical to construct, and consume mixing energy but they still generate an energy surplus in the form of digester gas.

Using definitions found in US regulations, anaerobic digestion produces class B Biosolids suitable for land application as defined by 40 CFR Part 503. However, with increased public scrutiny and growing local regulation of land application of Class B biosolids, some utilities have become concerned about continued reliance on this practice. Consequently, they are exploring options for improving solids treatment to achieve Class A or similar enhanced treatment standards. Much of the recent focus for achieving Class A stabilization has been on thermal drying.

Thermal drying is an add-on process to biosolids management. Thermal drying technology will transform conventionally-digested biosolids into an attractive Class A enhanced-quality product that can be economically transported to distant points for use as a soil conditioner, an ingredient in a fertilizer blend, or an alternative fuel.

Thermal drying involves the application of heat to evaporate water from the solids. It reduces the moisture content in biosolids to a level far below that achievable by conventional mechanical dewatering methods, improving the handling characteristics and reducing the mass of material transported and used off site for final use. The product retains its nutrient value after drying and is suitable for beneficial use as a fertilizer or fuel.

In the absence of digestion, one of the major operating costs for a thermal drying facility is the cost for energy that is required to evaporate water from the mechanically dewatered solids. Energy for heat drying is typically furnished by combusting fossil fuels such as natural gas or fuel oil. Due to the cost for fuel, coupled with the emphasis on economizing the use of fossil fuels, many treatment facilities are looking for opportunities to replace the fossil fuels with renewable fuels for thermal drying.

Where thermal drying is used in conjunction with an existing mesophilic digestion process for enhanced treatment, the pairing of these two processes can provide an opportunity to maximize the overall energy equation. The digester gas can offset the energy requirements for drying and, in return, waste heat recovered from dryer condensate can provide process heating for the digesters. The portion of dryer energy needs that can be provided by digester gas typically depends on the efficiency of the mechanical dewatering step upstream from drying, the volatile solids concentration of the solids, digester performance and dryer operations.

ENERGY AND MASS BALANCE
To illustrate the synergy between anaerobic digestion and thermal drying, this paper presents the mass and energy balance for a hypothetical 190 MLD wastewater treatment plant. The energy balance is based on using all the digester gas for drying and recovering energy from the dryer condensate for process heating without using fossil fuel. The solids processes included in this analysis and the process parameters used to develop the energy equation are discussed in the following sections.

Mesophilic Anaerobic Digestion
Anaerobic digestion has two major synergistic impacts on the drying process. First, digestion reduces the size of the dryer by 30 to 50%, depending on the digestibility of the sludge. Second, the energy content in the lost solids is extracted as digester gas, which is suitable for use in the dryer. There are a host of other relevant benefits including less odor on land application, better particle size distribution and denser final product.

Digester gas has a typical fuel value of 22,300 kJ per normal cubic meter and can be used as a fuel for drying. Digester gas is primarily composed of methane and carbon dioxide, but may include contaminants such as hydrogen sulfide (H₂S) and organic silicon compounds, commonly referred to as siloxanes. The gas will also be saturated with moisture at the operating temperature of the digesters. Digester gas quality requirements vary depending on the gas utilization equipment. If digester gas is to be used as an energy source for thermal drying, the quality requirements are low compared...
to a combined heat and power (CHP) system. Dryers can tolerate the contaminants in digester gas and require minimum gas cleaning. It is recommended that the moisture in the gas be reduced to avoid condensation in the valves and the burner nozzles.

The digester heating requirements for this analysis were determined based on maintaining the digestion process at mesophilic temperatures (35°C). The heating requirements for digestion consist of two parts – (1) heat required to raise the incoming feed to the operating temperature of the digesters, and (2) heat required to replace the transmission heat losses through the digester walls and the roof. The transmission losses from a digester depend on the ambient air temperatures and can be higher in northern climates compared to southern and coastal locations. Typically, transmission losses account for only a small fraction of the total digester heating load.

Mechanical Dewatering

Efficient dewatering is critical to the overall energy balance of a thermal drying facility because it is more energy efficient to mechanically dewater solids rather than to thermally dry them. The capacity and operations of the post-dewatering drying step are affected by the moisture content of the dewatered cake. Since dryers are typically sized based on evaporative capacity requirements, an efficient dewatering process will allow a greater quantity of solids to be dried in a given size of dryer. The effectiveness of the dewatering process will also vary depending on the type of feed solids (primary solids vs. secondary solids) and upstream processing (digested solids vs. raw solids). Based on operating experience elsewhere, primary solids and digested solids are easier to dewater than secondary solids. Depending on the capture efficiency of the dewatering step, a small fraction of solids is also returned to the liquid treatment processes with the centrate.

The most widely used technologies for solids dewatering are belt filter presses (BFP) and centrifuges. In comparison to BFPs, centrifuges are enclosed, making for a cleaner operation within the dewatering building and better capture of odors. Centrifuges typically achieve approximately 2 to 3% higher cake solids than belt presses. On the flip side, centrifuges have a higher electricity usage than belt presses, slightly higher polymer consumption, and maintenance requirements. Despite the higher operating and maintenance costs, potential exists for savings with labor and downstream handling due to higher solids concentrations compared to belt presses. This mass and energy balance was developed based on the use of centrifuges for solids dewatering.

Thermal Drying

There are a number of different drying technologies available, and technology selection is typically based on the evaporative capacity requirements and the final product quality. Drying technologies are generally categorized as direct or indirect systems. In direct dryers, the solids to be dried are heated by direct contact with a hot gas. With indirect dryers, heat is transferred by conduction from the heat carrier to the biosolids through a metal surface. The indirect drying systems are typically associated with small to medium-sized facilities (less than 10 dry tonnes per day[dtpd]) due to the limited evaporative and materials handling capacities of these units. Direct contact systems, except the belt dryer, are used for larger applications (greater than 10 dtpd).

The majority of drying facilities in the United States use rotary drum dryers. This paper uses the process parameters associated with a rotary drum dryer for the energy and mass balance. In a rotary drum dryer, the exhaust gas typically passes through a condenser-scrubber unit to scrub the gas and condense the water evaporated from the solids being dried. Plant effluent is used to cool the gas for condensing the water vapor. In the process of cooling the gas, the plant water is heated and combines with the water vapor to provide a hot water stream at about 57°C to 63°C, which could be used to heat the digestion process. The heat recovery techniques may also apply to other dryers that use a condenser to remove moisture from the dryer exhaust. Heat may be recovered from the dryer condensate stream using a concentric-tube or spiral heat exchanger. A natural gas-fired boiler should be provided to heat the digester during startup, and to provide heating energy in case of equipment downtime.

One key to optimum use is that both processes are operated continuously to use the digester gas as it is produced, avoiding the need for expensive gas storage.

<table>
<thead>
<tr>
<th>No.</th>
<th>Process Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Feed Solids Concentration</td>
<td>%TS</td>
<td>5%</td>
</tr>
<tr>
<td>2.</td>
<td>Volatile Solids Concentration in Feed</td>
<td>% of TS</td>
<td>75%</td>
</tr>
<tr>
<td>3.</td>
<td>Volatile Solids Reduction (VSR) in the Digesters</td>
<td>%</td>
<td>45%</td>
</tr>
<tr>
<td>4.</td>
<td>Digester Gas Yield</td>
<td>m³/kg VSR</td>
<td>1.0</td>
</tr>
<tr>
<td>5.</td>
<td>Heating Value of Digester Gas</td>
<td>kJ/m³</td>
<td>22,260</td>
</tr>
<tr>
<td>6.</td>
<td>Digestion Process Temperature</td>
<td>°C</td>
<td>35</td>
</tr>
<tr>
<td>7.</td>
<td>Feed Sludge Temperature</td>
<td>°C</td>
<td>15.5</td>
</tr>
<tr>
<td>8.</td>
<td>Digester Transmission Losses</td>
<td>% of Total Load</td>
<td>10%</td>
</tr>
</tbody>
</table>

Table 1 – Process Parameters and Assumptions
Process Parameters and Assumptions Made in the Analysis
The process parameters used in developing the mass and energy balance for the facility are typical and represent a ‘composite’ design of many digestion and drying facilities. Process parameters used for the mass and energy balance are provided in Table 1. Figure 1 shows the overall energy balance for the facility.

Impact of Changes in Digestion and Dewatering
Changes in some of the digestion and dewatering parameters can impact the overall energy balance computed for the typical case illustrated in Figure 1. The sensitivity of the results to changes in digestion and dewatering parameters are discussed in the following sections.

Effect of Volatile Solids Concentration in Digester Feed
Higher volatile solids concentration in the digester feed will generate more digester gas at the same volatile solids reduction. There will also be a decrease in the solids flow to the thermal dryers downstream. The higher energy available from digestion, coupled with the decrease in solids to drying, will lower the auxiliary fuel requirement for drying as seen in Figure 2. At 71% volatiles content, the energy available from the digester gas can sustain the drying operation, eliminating the need for auxiliary fuel. Since the fraction of volatiles in the feed is dependent on the waste source, this parameter cannot be changed easily. However, the organics in biosolids have a shelf life and long residence times in the collection systems, and the liquid treatment processes can lower the volatility of the solids, affecting the energy recovery potential.

Effect of Dewatered Solids Concentration
As seen in Figure 3, the higher the solids concentration of dewatered cake, the lower the dryer capacity requirements. The dryer capacity is often erroneously based on the dry solids feed to the dryer and the significance of dewatering is overlooked. The dryer capacity requirement at a solids concentration of 15% solids is approximately double that required at 25% total solids. Reducing the amount of water to be evaporated in the dryer through better dewatering will also result in lower energy requirement for drying.

Under typical operating conditions, the feed solids to drying are dewatered to approximately 25% solids. The need for auxiliary fuel can nearly be eliminated at this concentration. Solids concentrations exceeding 30% are not recommended as this may adversely affect the characteristics of the dried product.

Effect of Dryer Operating Schedule
Continuous operation of both digestion and drying processes is the key to optimum energy utilization. Table 2 lists the change in capacity and fuel requirements for a dryer operating on a five days per week schedule compared to one operating on a continuous seven-day schedule. A weekly batch operation of the dryer (24 hours per day, five days per week) will increase the moisture loadings to the dryer, requiring larger quantities of auxiliary fuel to meet the energy needs in excess of the digester gas. It is not economically feasible to provide digester gas storage greater...
than the equivalent of a few hours of production. Consequently, non-continuous operation of the dryer will require the digester gas to be diverted to a boiler to produce hot water for digester heating. Alternatively, it may be flared or used in an engine generator.

For less than continuous operation of the dryers, a ‘wide spot’ will be required for digested biosolids storage if the digesters are operated at fixed liquid levels. Digesters operating at varying levels may be able to accommodate the excess solids when the dryers are not in operation.

**BENEFICIAL USE OF DRIED PRODUCT**

The quality of the heat-dried product will depend on the dryer feed characteristics and dryer operations. Mastering the thermal drying process will require an understanding of how the upstream solids processes can affect dryer operations and dried product quality. The solids processes upstream can impact the dryer feed characteristics, which in turn can affect the physical characteristics of the dried product, such as durability, potential for dusting, and propensity for odors. Ensuring consistent solids characteristics to the dryer system will allow more consistent operation of the dryers and good final product quality.

Thermally dried biosolids product has the potential to be marketed to a broad spectrum of users. However, many of these markets may not be familiar with the use of heat-dried biosolids. Therefore, it may be prudent for facilities to conduct an assessment of the local and regional market opportunities for the dried product before investing in a biosolids drying facility. This assessment should focus not only on the capacity of various outlets to accept the end product, but also, the qualities and characteristics of the dried biosolids that would fulfill the requirements of prospective customers.

Generically, there are four primary segments into which dried biosolids can be marketed:

- **Bulk Distribution to Agriculture.** The heat-dried product can either be sold directly to individual growers or to biosolids land application companies that service these end-users.
- **As a Constituent in Dry, Bulk-blended Fertilizers.** This outlet is comprised of many diverse agricultural programs, including sod farms, flower gardens, fruits orchards, and nurseries. The heat-dried product can be marketed to firms that manufacture fertilizers by blending multiple dry ingredients to produce an end product that meets the requirements for a specific application.

- **Distribution to Local Government Agencies.** A market segment that is sometimes overlooked is comprised of public agencies and recreational facilities. Local governmental agencies and communities will typically consider use of locally-produced dried biosolids in their grounds maintenance programs.
- **Non-traditional Use as a Fuel.** An outlet for dried biosolids that is well established in Europe and is beginning to develop in North America is use of the product as a fuel. Dried biosolids generally have a fuel value of approximately 17,000 to 22,700 kilojoules per kilogram of dry solids and may be able to replace coal or other solid fuels in industrial applications ranging from co-generation to cement manufacturing. Anaerobic digestion upstream from drying lowers the fuel value of the dried product since a portion of the organic matter is destroyed in the digesters.

As with any new product, marketing locally produced dried biosolids requires some time period during which demand must be created and, in most cases, it may take several years before revenue-generating demand approaches the product supply. Lack of dust and odors are critical physical factors in assessing dried biosolids product and, irrespective of the processing system, it is necessary to take steps to control the dust and

### Table 2 – Effect of Operating Schedules on Evaporation Capacity and Fuel Requirements for Drying

<table>
<thead>
<tr>
<th>Dewatered Cake %TS</th>
<th>Energy from Digester Gas kJ/h</th>
<th>24 h/d – 7 d/wk Operation</th>
<th>24 h/d – 5 d/wk Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dryer Capacity kg H₂O/h</td>
<td>Energy Requirement MJ/h</td>
<td>Dryer Capacity kg H₂O/h</td>
</tr>
<tr>
<td>15.0%</td>
<td>14.2</td>
<td>6,680</td>
<td>24.7</td>
</tr>
<tr>
<td>18.0%</td>
<td>14.2</td>
<td>5,350</td>
<td>19.9</td>
</tr>
<tr>
<td>20.0%</td>
<td>14.2</td>
<td>4,690</td>
<td>17.3</td>
</tr>
<tr>
<td>25.0%</td>
<td>14.2</td>
<td>3,500</td>
<td>13.0</td>
</tr>
<tr>
<td>30.0%</td>
<td>14.2</td>
<td>2,710</td>
<td>10.0</td>
</tr>
</tbody>
</table>

**Figure 2 – Effect of Volatile Solids in Digester Feed on Dryer Capacity and Energy Requirements**

(Based on dewatered cake solids concentration of 25% TS)

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**Notes:**

- The table above presents the results of a study on the effect of operating schedules on evaporation capacity and fuel requirements for drying.
- The data is based on the capacity of various outlets to accept the end product, the qualities and characteristics of the dried biosolids, and the requirements of prospective customers.
- Distribution to local government agencies and non-traditional use as a fuel are also discussed in the context of the study.

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**Figure 2 – Effect of Volatile Solids in Digester Feed on Dryer Capacity and Energy Requirements**

(Based on dewatered cake solids concentration of 25% TS)
odors in the dried biosolids prior to marketing. Anaerobically digested biosolids usually exhibit slightly lower total nitrogen and phosphorus concentrations than raw solids. Total nitrogen concentrations typically range from 3% to 6% (dry weight basis) and total phosphorus ranges from 2% to 3% (dry weight basis).

CONCLUSIONS AND RECOMMENDATIONS
Anaerobic digestion in the mesophilic phase coupled with heat drying of solids can economically produce a Class A biosolids product with value as fertilizer, soil conditioner or fuel. A combined digestion and drying facility can be self-sufficient with regards to fuel, assuming a volatile solids reduction of about 45% and dewatering to between 23 to 25% cake solids. Much of the heat created by burning digester gas in the dryer can be recovered to heat the digester itself.

The volatile solids concentration in the digester feed and digester performance has a major impact on digester gas production and the quantity of solids to drying. Therefore, to optimize energy recovery from biosolids, it is imperative that the carbon (volatile solids) in the solids be preserved through the liquid processing steps to the extent possible so that the volatile solids concentration in the digester feed can be maximized for energy recovery.

In short, wastewater treatment facilities taking a more holistic approach to process design can benefit from the synergies existing between processes that would help in optimizing the overall energy equation.

Figure 3 – Effect of Dewatered Cake Concentration on Dryer Capacity and Energy Requirements

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