FACT SHEET

Anaerobic Digestion Fundamentals

Anaerobic digestion is a sustainability staple at resource recovery facilities. In addition to performing vital solids treatment processes such as stabilization and volatile solids reduction, anaerobic digestion also generates biogas that can be used at the resource recovery facility to generate heat and power.

Anaerobic digestion is a solids stabilization process commonly used at municipal and industrial water resource recovery facilities (WRRFs). The primary objective of anaerobic digestion is to convert the microbiological cells and other solids generated during the treatment process to a stable end product. Other solids stabilization processes include aerobic digestion, composting, thermal drying, thermal oxidation, and alkaline stabilization.

Anaerobic digesters typically consist of concrete or steel tanks and receive solids from separation processes in the liquid treatment train. Solids may be comprised of settled material from primary clarification and secondary clarification, as well as scum and grease. Fats, oils, and grease (FOG) or food waste from sources outside of the WRRF also may be fed directly to digesters in some applications.

Similar to other stabilization processes, anaerobic digestion reduces odors and pathogens in the solids stream. Following stabilization, the digested product, referred to as biosolids, may be removed from site for disposal or processed further to reduce water content in preparation for disposal or beneficial reuse.

The primary benefit of anaerobic digestion compared to other forms of solids stabilization is the energy recovery potential. Unlike the other commonly used stabilization processes, anaerobic digestion generates a biogas comprised primarily of methane and carbon dioxide that may be recovered for beneficial use such as heat or power generation.

The potential for resource recovery has led to increased use of anaerobic digestion in recent decades.

PROCESS DESCRIPTION

Anaerobic digesters may receive solids from upstream processes in the liquid treatment train or FOG and food waste from outside sources such as restaurants and other commercial or industrial facilities.

The solids from upstream processes typically are comprised of primary sludge, secondary sludge, scum, grease, and/or other solids and liquids that may enter the solids collection system (including grit). Solids handling pumps like progressive cavity or rotary lobe pumps typically convey solids to the digester tanks.

Intermediate steps may be implemented prior to digestion to improve the process efficiency or prevent excessive maintenance on tanks or equipment. Grinding helps prevent maintenance issues by shredding large or stringy material into smaller components. Screening also prevents maintenance issues by removing large or stringy materials. Degritting improves process efficiency by preventing accumulation of grit inside digester tanks.

Grit is particularly concerning. The accumulation of settled grit and other inert solids within digester tanks reduces the effective treatment or digestion volume. This digestion capacity reduction hinders the stabilization performance, reduces gas production, and increases the frequency of tank maintenance and cleaning.

Solids blending (combining separate streams such as primary sludge and waste activated sludge into one feedstock) and temporary storage in a holding tank also may be implemented upstream of the anaerobic digestion process. Blending and storage produces a more homogeneous loading and minimizes digester feed flow variability. Feed variability (in quality or flow) may cause digester foaming issues and require more maintenance.

An additional intermediate step prior to digestion may include solids thickening. In this process, the water content of primary and/or waste activated sludge is reduced. Process examples include gravity thickening, rotary drum thickening, and gravity belt thickening. By reducing the overall volume of digester feed sludge, thickening may reduce the equipment and tankage capacity required for digestion, conveyance, or storage, as well as the energy required for digester heating, and chemical use for additional conditioning (if required).

Following any intermediate processing or thickening, solids are conveyed to digesters. Many different digester configurations, shapes, and flow patterns are available depending on the quality of the digester feed and the primary process objectives. These process objectives may be based on the degree of volatile solids reduction, gas production, or pathogen destruction required. Table 1 (p. 2) provides a brief introduction into some of the digester process options.

Table 1. Common digester configurations

Anaerobic digestion method	Operation	Advantages
Mesophilic	Temperatures may range from 35°C to 39°C	• most common digestion method • produces biosolids and biogas for beneficial use
Thermophilic	Temperature may range from 50°C to 57°C	• improved pathogen destruction • higher quality biosolids produced • improved gas production • reduced volume requirements (due to increased reaction rate)
Temperature-phased	Mesophilic and Thermophilic operation	• reduced thermophilic heating volume • improved volatile solids destruction • increased gas production
Acid/gas phased	Multiple phases including acid stage (with pH conditions below 6.0) and gas stage (with neutral pH conditions)	• improved volatile solids destruction • foaming control

Mesophilic digestion is by far the most common method of digestion, followed by thermophilic. Other methods, such as temperature-phased anaerobic digestion (TPAD) and acid/gas-phased anaerobic digestion (AGAD), are far less common and are less rigidly defined compared to mesophilic and thermophilic digestion methods. For example, the TPAD configuration may include an initial acidic stage, and the AGAD configuration may include an initial thermophilic stage.

Regardless of the configuration, the objective of digester operation is to create an environment that promotes organic decomposition and reduction of inorganic matter. This is accomplished primarily by maintaining a certain temperature (depending on the digestion method) and ensuring sufficient mixing.

External heat exchangers typically are used to maintain sufficient temperature within the digester. Spiral type heat exchangers and water bath type heat exchangers increase the temperature of solids by exposing a pipe containing solids to high temperature water. As the solids pass through the heat exchanger piping, energy (heat) is transferred from the hot water to the solids. Solids (at an elevated temperature) then return to the digester to increase or maintain the temperature of the contents.

Numerous methods are available to maintain digester contents in suspension, including pumping from one location within the tank to another. This uses an external draft tube or an external centrifugal pump. Mechanical mixing via an impeller or linear motion mechanism located within the tank or gas injection are other mixing methods.

The biogas that forms during anaerobic digestion is a result of the biological decomposition of organic matter taking place in the absence of oxygen. Methane (CH4) makes up 65% to 70% of biogas, while carbon dioxide (CO2) comprises about 25% to 30%. Trace quantities of nitrogen (N-2), hydrogen (H2), and hydrogen sulfide (H2S), water vapor, and other gases make up the difference.

The energy potential of methane makes biogas a valuable resource as mentioned above. The heat produced by burning biogas fuel in a boiler may be utilized to heat water for use in a heat exchanger or for the facility's building heating system. Cogeneration or combined heat and power (CHP) systems are used to produce heat and to convert the energy contained in biogas to useable electrical energy. Microturbines, gas turbines, or internal combustion engines connected to generators are used to produce electricity, which may be used onsite or exported to an external power grid.

WEF Photos

Higher-value fuels such as compressed natural gas (CNG), liquid natural gas (LNG), or methanol may also be produced from biogas. While these fuels are considered higher-value, the processes for producing and using CNG, LNG, and methanol are more complex in comparison to using biogas for heat and power generation. As technology advances, the use of biogas to produce these higher-value fuels may become more common.

Prior to use, biogas must be pretreated to remove impurities and other substances which may cause maintenance and process efficiency issues. The water vapor present in biogas reduces process effectiveness, and may be removed by sloping biogas piping toward sediment/drip traps that collect condensed water vapor for disposal.

Hydrogen sulfide, when combined with water vapor, forms a weak acid that may damage biogas piping or equipment. Passing biogas through wood chips impregnated with iron sponge, biological scrubbers, or activated carbon help remove hydrogen sulfide from biogas. Liquid phase oxidation is an alternative removal method.

Siloxanes present in biogas convert to silicon dioxide particles or sand when heated (for example, in a boiler, engine, or turbine). These particles may cause damage and reduce equipment life. Adsorption using activated carbon or condensation may be employed to remove siloxanes.

Beside biogas, digestion also produces biosolids. Biosolids may be conveyed to a secondary digester (if present) or the mechanical dewatering process. Alternatively, — and depending on regulations and WRRF operation — the biosolids may be collected and hauled to an offsite location for final disposal or further processing.

Secondary digester tanks may be employed to enable liquid–solid separation of biosolids. This separation produces a liquid called supernatant as well as thickened biosolids. Supernatant is returned to the head of the WRRF (usually the headworks), while the thickened biosolids may be processed further or hauled offsite for final disposal.

Dewatering is the most common form of biosolids processing post-digestion. The objective of dewatering is to reduce the water content of biosolids; this reduces hauling costs. The dewatered "cake" that is generated from dewatering may be landfilled or, depending on the quality of the cake, added to soil as an amendment. Numerous technologies are available to mechanically dewater solids; common equipment types include centrifuges, screw presses, belt filter presses, and rotary presses. Solids drying beds are a more passive dewatering approach and require more space and additional labor to produce dewatered cake. The liquid removed from solids during dewatering typically is returned to the head of the WRRF.

Incineration is an alternative form of biosolids processing and may be accomplished using multiple hearth reactors or fluidized bed reactors. End products include carbon dioxide, water, and ash. The objectives of incineration include volume reduction in preparation for final disposal and energy recovery.

DESIGN

There are three main stages of anaerobic digestion: hydrolysis, fermentation, and methanogensis. All three occur simultaneously and in the same vessel.

During hydrolysis, cells that were instrumental in biological treatment in the liquid train are broken down into a soluble form. Fermentation follows hydrolysis. During this stage, the soluble products formed during hydrolysis are converted to a mixture of volatile fatty acids (a process called acidogensis) and, then, the mixture of volatile fatty acids is converted primarily to acetic acid, carbon dioxide, and hydrogen (a process called acetogenisis). The final stage is methanogensis, which involves the conversion of acids and hydrogen (formed during fermentation) to methane and carbon dioxide. The proper design of anaerobic digesters helps maximize the effect and success of each of these three stages.

While there are numerous styles and operational strategies, most anaerobic digesters are operated as single stage mesophilic reactors. Table 2 (p. 3) provides typical design criteria for high rate mesophilic digesters.

Table 2. Typical high rate mesophilic digester design criteria

Parameter	Typical target range
Temperature	95°F to102°F
Volatile solids loading rate	0.12 to 0.16 $lb/ft^3 \cdot day$
Feed percent solids	4% to 7%
Solids retention time	15 to 20 days

Table adapted from *Design of Municipal Wastewater Treatment Plants (Manual of Practice No. 8),* published by the Water Environment

Numerous factors greatly affect the construction and operation of anaerobic digesters and must be considered during design. The following section summarizes a few of these factors.

Tank volume and retention time

When sizing an anaerobic digester and selecting a design solids retention time (SRT), the engineer must consider such factors as biochemistry, microbiology, industrial contributions, and regulatory requirements. Simplified empirical methods are available for use during design. High rate mesophilic digesters may employ an SRT between 15 and 30 days. In general, the longer the SRT, the more volatile solids reduction.

Volatile solids reduction

Volatile solids reduction is a common metric used to evaluate digestion effectiveness, but is difficult to quantify for design as it is greatly affected by both operating conditions and solids feed variation. The volatile solids loading rate is a design parameter that may be used to size digester tanks.

Gas production and collection

Typically, gas is produced at a rate of about 13 to 18 ft3/lb volatile solids reduced. Methane may account for up to about 70% of the total volume of gas produced during digestion. Gas produced during anaerobic digestion is collected under the digester tank cover, where it is temporarily stored prior to its ultimate use. Numerous cover styles and types are available, including fixed (immobile), floating, and membrane covers. During cover selection and design, the engineer should consider gas production, thermal requirements, and odors, as well as foam and scum control.

Tank shape

The three most common shapes are cylindrical (with slightly sloped tank floor), egg-shaped, and the “German style”, which features a cylindrical tank with more steeply sloped bottom and top sections. Most anaerobic digester designs in the U.S. feature conventional cylindrical tanks.

Mixing

Multiple mixing options are available. Common examples include external or internal draft tubes, which pump contents from one section of the digester to another via tubes located, respectively, on the tank exterior or interior; pumps, which receive contents from one section of the digester and pump to another section; and submersible mixers, which stir contents within a digester via impellers.

Biosolids classification

According to the U.S. Environmental Protection Agency’s regulation at 40 CFR Part 503, there are two levels of pathogen reduction: Class A and Class B. These designations and the resulting processes to achieve them affect the quality and ultimate use of biosolids. The biosolids that result from Class A pathogen reduction may be directly applied to land for beneficial reuse. Reaching Class A requires additional treatment during digestion, for example exposing digester contents to higher temperature. More regulations exist for the end use of biosolids that result from Class B pathogen reduction. To meet Class B pathogen reduction, anaerobic digesters must be operated for a minimum SRT of 15 days and a temperature between 95°F and 131°F.

OPERATION AND MAINTENANCE

Table 3 (p. 4) provides typical operating parameters for mesophilic anaerobic digesters.

Table 3. Typical mesophilic digester operating parameters

Parameter	Value
VSS destruction	45% to 55%
pH	6.8 to 7.2
Alkalinity	2500 to 5000 mg/L as $CaCO_3$
Methane content of biogas	60% to 65% (by volume)
Carbon dioxide content of biogas	35% to 40% (by volume)
Volatile acids (VA)	50 to 300 mg/L as VA
Volatile acid: alkalinity ratio	<0.3 mg $CaCO_3$/ mg VA
Ammonia	800 to 2000 mg/L as N

Table adapted from *Design of Municipal Wastewater Treatment Plants (Manual of Practice No. 8),* published by the Water Environment Federation and McGraw Hill

The operations and maintenance plan for anaerobic digesters focuses on maintaining conditions that promote the digestion process, including pH, temperature, and alkalinity. Tank foaming and odor must be considered and addressed to prevent additional maintenance or nuisance issues. And, in general, tanks should be emptied periodically to enable operators to check mechanical equipment and clean tank interiors. The table below provides additional information on O&M typical of conventional mesophilic digestion.

Table 4. O&M Typical of Conventional Mesophilic Digestion

O&M activity	Effect
Maintaining pH between 6.8 and 7.5	Methanogens are sensitive to variations in pH. Operating outside of this range may reduce methane generation and impair overall digestion performance.
Maintaining Temperature between 95°F and 102°F	Methanogens are sensitive to variations in temperature. Operating outside of this range or even changing digester temperature more than about 2°F per day may reduce methane formation, increase foaming, and impair overall digestion performance.
Maintaining sufficient alkalinity	Sources of alkalinity like ammonia and bicarbonate are produced during digestion and help maintain pH. A well-performing digester should not require alkalinity supplementation. The need for alkalinity supplementation with chemicals such as sodium bicarbonate and lime to stabilize pH is indicative of overall system imbalance. Further evaluation may be necessary.
Minimizing tank foaming	Foaming impairs performance by reducing the active digestion volume; this may lead to lower volatile solids reduction and biogas production, short circuiting of pathogens, mechanical equipment damage, and foam overflows or spills. Foaming may result from the presence of chemical surfactants, biological surfactants, or filamentous organisms. Foaming may be exacerbated by unstable operations such as highly variable loading rates or mixing. Maintaining constant digester feeding (rather than loading in batches) helps limit tank foaming issues.
Minimizing odor	Odorous compounds such as hydrogen sulfide and ammonia are produced during digestion. The installation of digester tank covers limits the effect of nuisance odors to the surrounding environment.
Tank cleaning	Digester tanks should be removed from service periodically for cleaning and inspection. While offline, operators can check or repair any mechanical equipment installed within the tank and inspect the tank itself for structural deterioration. Additionally, grit and scum, accumulates within digestion vessels and limits effective/treatment volume, and should be removed while the tank is offline.
Maintaining safe work spaces	Biogas is a flammable substance. The lower explosive limit (LEL) for methane in the air is 5%. Furthermore, empty digesters are classified as confined spaces. The immediately dangerous to life or health (IDLH) limit for methane in the air is 0.5%. To ensure safety and minimize risk, air monitors should be installed where appropriate and operators should follow all safety precautions when working around digesters and related equipment.

References

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Acknowledgments

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Additional Resources WEF Resources

Resource	Description
Solids Process Design and Management (2012)	This publication is intended for use by professionals engaged in the design, approval, and operation of municipal solids treatment and disposal systems. This publication includes material on planning, solids production and characterization, conveyance, conditioning, thickening, waste minimization, anaerobic and aerobic digestion, dewatering, composting, alkaline treatment, disinfection and stabilization, thermal drying, thermal oxidation, pyrolysis and gasification, transport and storage, odor management, sidestreams, instrumentation and monitoring, land application and product distribution, landfill management, emerging technologies, and treatment and utilization of green gases.
Biogas Production and Use at Water Resource Recovery Facilities in the United States (2013)	This report highlights existing anaerobic digestion systems at U.S. Water Resource Recovery Facilities, as well as current uses of, and potential future opportunities for, using biogas produced by these facilities.
Biogas Utilization: A Regional Snapshot in Understanding Factors that Affect Water Resource Recovery Facilities (2015)	The goal of this report is to summarize “sprint” data collection activities, which took place during 2014 as part of a larger collection effort aimed at determining the beneficial use of biogas within the water environment industry. As data continues to be supplemented, additional regional reports will be released. The site-specific data can be found at www.biogasdata.org.
Technical Practice Update: Direct addition of High Strength Organic Waste to Municipal Wastewater Anaerobic Digesters (2010)	The main purpose of this Technical Practice Update (TPU) is to provide a high-level overview of some of the potential benefits and challenges of direct co-digestion of high-strength organic wastes with municipal wastewater sludge.
Moving Toward Resource Recovery Facilities (2014)	This book provides an overview of the fundamental drivers for resource recovery from wastewater and presents the basic case for resource recovery. It also provides an overview of state-of-the-art technological approaches to resources recovery and provides general guidance on the applicability of recovery technologies for the cross section of facility types. This allows facilities to take steps toward recycling a greater number of otherwise lost resources.