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ANAEROBIC DIGESTION EFFLUENTS AND PROCESSES: THE BASICS

Anaerobic Digestion Systems Series

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ANAEROBIC DIGESTION EFFLUENTS AND PROCESSES: THE BASICS

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Abstract
Anaerobic digesters are used worldwide to produce bioenergy and sustainably treat organic waste from municipal, industrial, and agricultural operations. This fact sheet reviews the basic elements of anaerobic digestion systems, including the types of digesters, biochemistry of the digestion process, typical process conditions, and measurements used to evaluate influent and effluent as well as process stability. The Anaerobic Digestion Systems Series provides research based information to improve decision-making for incorporating, augmenting, and maintaining anaerobic digestion systems for manures and food by-products.

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Anaerobic Digestion Effluents and Processes: The Basics

Introduction

Anaerobic digesters are utilized worldwide to produce **bioenergy** and sustainably treat **organic waste** from municipal, industrial, and agricultural operations. In many diverse settings, **anaerobic digestion** (AD) has been shown to reduce odors and pathogens, stabilize waste streams through reduction in solids and organic content, and mitigate **greenhouse gas** (GHG) emissions compared to other waste management options (Abbasi et al. 2012; Martin 2004).

Primary goals for AD vary by sector. In municipal settings, the primary goal is to treat waste streams and reduce the volume of wastewater treatment sludge. Flaring the produced **biogas** is common in this setting, although at some facilities (particularly in larger cities) **renewable natural gas** is produced.

In industrial settings, such as the food and beverage processing industry, the primary goal is also waste treatment. This reduces downstream treatment costs and in some cases allows treated wastewater to be incorporated into local sewer systems. In contrast, **manure management** and bioenergy production are both important at large-scale **concentrated animal feeding operations** (CAFOs). Farmers who operate CAFOs often sell upgraded biogas or co-products and view AD as a revenue generating opportunity.

Anaerobic digestion produces a number of outputs in the solid, liquid, and gaseous form (Figure 1). Biogas produced during AD is predominantly used for the production of electricity and heat, called **combined heat and power** (CHP). Other primary products include a solid **fiber** (often used for animal bedding in agricultural settings) and a nutrient-rich liquid that can be applied to agricultural soils.

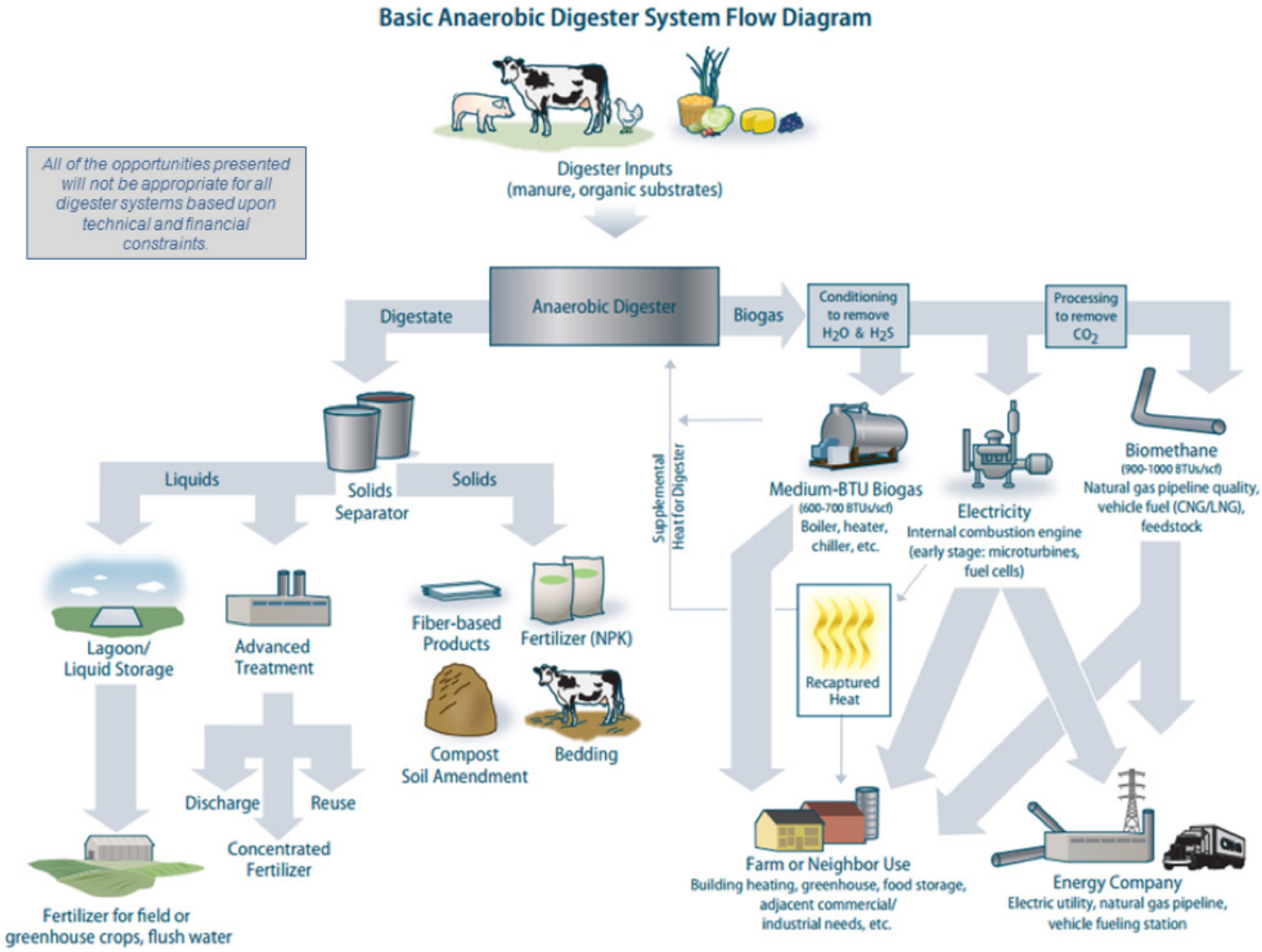

Figure 1. Anaerobic digester system flow diagram. Image: EPA (2013).

New technologies have allowed for each of these primary products to be additionally processed into products with greater market potential:

- Renewable natural gas (RNG) from the biogas after **biogas scrubbing** to remove **carbon dioxide** (CO_2), **hydrogen sulfide** (H_2S), and water vapor.
- **Compressed natural gas** (CNG) or **liquefied natural gas** (LNG) from the RNG.
- **Biofertilizers** from the liquids and solids **effluents**.

There are numerous individual and societal benefits to utilizing AD for waste treatment and bioenergy generation (Figure 1). However, the increased adoption of AD across the United States is dependent upon the development of profitable business plans based on revenues from multiple co-products, shown in Figure 1, and credits (e.g., carbon credits, renewable energy certificates, and renewable identification numbers).

The purpose of this publication is to provide stakeholders (such as third party developers and regulatory agencies) with an introductory document on AD with an emphasis on laboratory evaluations and a glossary of common terms and acronyms used in the industry (see Glossary). The objectives are to summarize the major types of digesters used for complex wastewaters, summarize AD biochemistry and process conditions, provide a more detailed overview of common AD laboratory evaluations and what they are used for, and briefly discuss optimization through **modeling.** This factsheet is part of a set of linked publications on the topic of Anaerobic Digestion Systems.

Types of Anaerobic Digesters

Anaerobic digestion is performed in a sealed and self-contained **reactor**. This allows for controlled mixing and constant temperature under anaerobic conditions, while also containing and capturing biogas. The typical **hydraulic retention time** (HRT) can range from 10 to 30 days in standard manure and municipal digesters. However, some industrial units treating highly **biodegradable** material with low solids content may have much shorter retention times—as low as hours. Conversely, **recalcitrant** material, such as agricultural residues, can take up to 60 to 120 days to digest.

The AD process takes place at a controlled temperature; in the US this is usually 35°C (**mesophilic**) or sometimes 55°C **(thermophilic)** (95°F or 131°F respectively). Higher thermophilic temperatures allow for rapid degradation of the organic material, as well as potentially higher biogas yield, albeit with debated concerns regarding impacts on process stability and cost (Metcalf and Eddy, Inc. 2003).

In the US, the most commonly used reactor designs for complex wastewaters are **complete mixed reactor** (CMR), **mixed plug flow reactor** (MPFR), **covered lagoon** (CL), and **plug flow reactor** (PFR) (Figure 2). These designs are better suited for handling **heterogeneous** materials of higher solids and organic content, such as manures, municipal wastewater, and agricultural residues. A variety of other configurations exist, such as **up flow anaerobic sludge blanket** (UASB), **fixed film anaerobic digester**, and **sequential batch reactor** (SBR). Technology choice is an important consideration, with the most appropriate choice being strongly tied to cost, operation, performance, project type, and goals. For more information on the different digester types typically used on CAFOs, refer to publications by the US Environmental Protection Agency's AgSTAR Program: AD 101: Anaerobic Digesters (EPA 2014a) and Overview of Biogas Technology (EPA 2010b).

Anaerobic Digestion Biochemistry

During AD, four general processes take place: **hydrolysis**, **acidogenesis**, **acetogenesis,** and **methanogenesis** (Figure 3). During hydrolysis, carbohydrates, proteins and fats are converted to smaller compounds: sugars, amino acids, and **fatty acids**, respectively. Hydrolysis is usually the rate limiting step for digesting only dairy manure (Ma et al. 2013a). Thereafter, these smaller compounds are broken down into **volatile fatty acids** (VFAs) during acidogenesis, and then into **acetic acid** and **hydrogen gas** (H_2) during acetogenesis. In the last step, **methanogens** consume acetic acid or H_2 to produce **methane/biomethane** (CH_4).

Anaerobic Digestion Conditions

Maintaining a specific **anaerobic microorganism** community in the reactor is essential for optimal CH_4 production. Sustaining an optimal ratio of **feedstock** to microorganisms is also important. Therefore, process conditions, such as temperature, **pH**, **organic loading rate** (OLR), and hydraulic retention time, should be held constant. If the environment changes, anaerobic microbes could become upset, causing lower growth rates or death. In addition, some feedstock may contain toxins that require monitoring and control so as to not adversely affect the biology and operation of the digester. For example, high ammonia (NH_3) content causes **ammonia inhibition**.

Anaerobic Digestion Laboratory Evaluations

Specific analyses can be used to better understand **influent**, effluent, biogas, digester performance, and microbiological qualities.

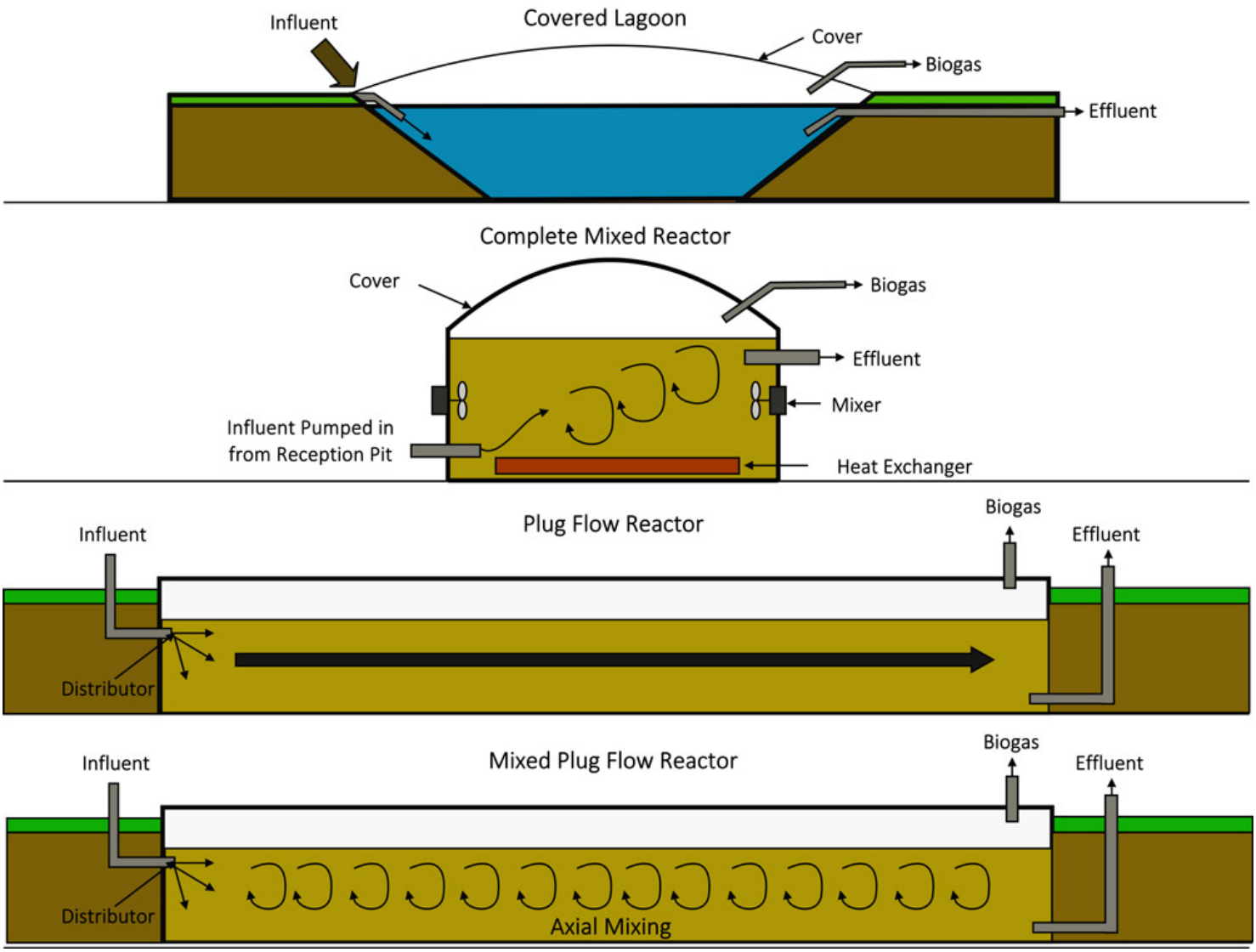

Figure 2. Basic AD reactor designs for complex, heterogeneous municipal and farm-based wastewaters. Modified from AgSTAR's fact sheet AD 101: Anaerobic Digesters (EPA 2014a).

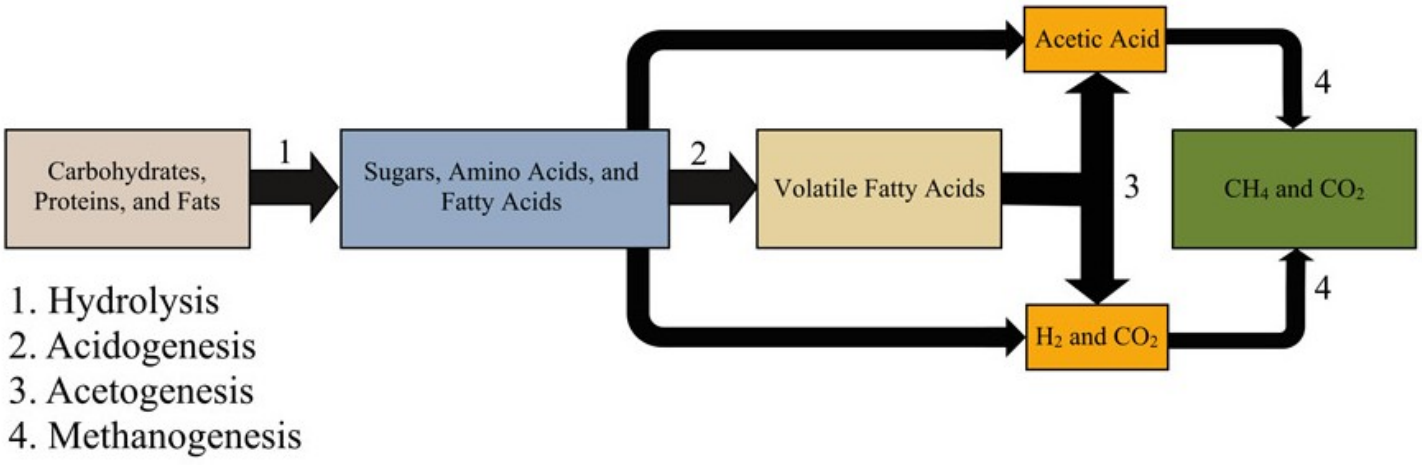

Figure 3. AD biochemistry process. Graphic by Nick Kennedy, modified from Amaya et al. (2013) and Hamilton et al. (2012).

These tests can be carried out within AD industry laboratories, using on-site resources. They can also be carried out through partnerships with active AD research laboratories at academic institutions. Analyses can be carried out for multiple purposes including (1) assisting in project design, (2) determining digester performance, (3) evaluating the causes of digester upsets, inhibition, or responses to changes, and (4) monitoring output qualities and content for ultimate product sales or effluent disposal. While not an exclusive list of all AD evaluations, this section summarizes common tests used in the industry to evaluate AD influent, effluent, and process stability.

Influent and Effluent Evaluations

Total Solids (TS), Volatile Solids (VS), and Fixed Solids (FS)

The **total solids** measurement represents the total dry matter of a material. It includes both organic and inorganic matter. The organic matter fraction is called **volatile solids**, and the inorganic fraction is called **fixed solids**. These values give information about the following factors:

- TS – influent thickness, thus advising on reactor operation and mixing regimes.
- VS – organic loading rate, thus advising on the degree to which the digester is being under or over fed.

Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand is a measure of the amount of biodegradable organic carbon in a material. It is calculated based on the oxygen depletion in a contained aqueous reaction from microorganisms metabolizing biodegradable material (Standard Method 5210; APHA 2012). Measurement of BOD is more time consuming and costly than VS/TS methods, but provides a better indicator on the amount of material that is actually converted by microorganisms.

Chemical Oxygen Demand (COD) and Soluble Chemical Oxygen Demand (SCOD)

Chemical oxygen demand is a measure of the total organic carbon in a material derived from both biodegradable and recalcitrant molecules. Soluble COD is a measurement of COD from a filtered sample, aiming to get a value for only very small suspended and dissolved solids that are supposedly readily biodegradable (EPA Method 410.4; EPA 1993).

Compared to BOD, COD is a more straightforward, less costly, and less time-consuming approach. However, COD could incur potential errors, as it is a chemically derived value and not a biologically derived value.

Volatile Fatty Acid (VFA)

The volatile fatty acid test measures small acids produced during the breakdown of complex organics (Standard Method 5560; APHA 2012). While a range of compounds is often reported or grouped as VFA, they usually comprise acids with 1 to 5 carbon units. Digester influent is usually already putrescent to some degree and thus contains existing VFA. More VFA is produced during the first three stages of AD, and removed via the last step of CH_4 production (see Figure 3). Thus, VFA can be an indicator of how "hot" the influent being fed into a digester is, with high influent VFA levels being readily, or perhaps too readily, digested. Volatile fatty acid is also an indicator of how effective or stable a digester is performing with effluent VFA levels preferably very low or non-detectible, as shown in Table 1 (Dong et al. 2011; Labatut and Gooch 2012). Certain instabilities can be attributed not just to the total VFA concentration but also to the form of VFA. Propionic and butyric acids are commonly monitored as indications of reactor instability.

Table 1. VFA concentration in AD influent and effluent samples. Zhao and Frear, unpublished data.

VFA	Concentration (ppm)	
	AD Influent	AD Effluent
Acetic acid (C2)	3,370	458
Propionic acid (C3)	340	116
Isobutyric acid (C4)	1,370	Not detected
Butyric acid (C4)	167	Not detected
Isovaleric acid (C5)	583	Not detected
Total	**5,830**	**574**

( ): Number of carbon units

pH

The pH of the AD reactor is another important parameter to measure, since healthy AD occurs between a pH of 7 and 8. Values lower than 6 could mean that the **substrate** has a low **pH buffer capacity** and that the methanogens are not utilizing the acids as fast as they are being made during acidogenesis and acetogenesis. Refer to ISO Method 10523 for details about measuring pH (ISO 2008).

Alkalinity

Alkalinity is the capacity of a material to neutralize acids. Carbonate and bicarbonate are the major contributors to total alkalinity (Standard Method 2320; APHA 2012); however, ammonia and phosphorus compounds can also contribute to the substrate buffer capacity.

High alkalinity in substrates is preferred, because this facilitates pH remaining between 7 and 8. Partial alkalinity or ratios such as the **Ripley Ratio** also allows prediction of pH control and digester stability (Ripley et al. 1986). The Ripley Ratio is the ratio of volatile acids to total alkalinity. In general, a ratio below 0.25 indicates a stable digestion process.

Total Ammonia Nitrogen (TAN) and Total Kjeldahl Nitrogen (TKN)

Nitrogen levels are not significantly reduced during AD. Therefore, similar influent and effluent concentrations should be expected. Relatively high concentrations of nitrogen (N) are present in the microbial **biomass**, attached to the suspended solids, and dissolved in the liquid fraction. For nutrient management purposes, it is important to know the amount of N in the liquid effluent before discharging into storage **lagoons** or application to fields.

The three major forms of N present in effluent include organic nitrogen, ammonia, and ammonium (NH_4^+). The anaerobic environment maintains low concentrations of both nitrate (NO_3^-) and nitrite (NO_2^-). **Total ammonia nitrogen** and **total Kjeldahl nitrogen** measures are used to determine N concentrations. Total ammonia nitrogen is a measurement of NH_3 and NH_4^+ (EPA Method 1690; EPA 2001b), while TKN is the sum of organic nitrogen, NH_3, and NH_4^+ (EPA Method 1687; EPA 2001c).

Results from these tests can help assess if additional treatment of the effluent to remove N is needed or if adjustments to an existing nutrient management plan are necessary. For more information on the issues related to nutrient overloading and the different ways to remove N from effluent, refer to WSU Extension Publication, *The Rationale for Recovery of Phosphorus and Nitrogen from Dairy Manure* (Yorgey et al. 2014).

Total Phosphorus (TP)

Total phosphorus is the sum of organic and inorganic P. Phosphorus complexes readily in both influent and effluent materials, and P is present in both the biomass and suspended solids. As with N, P levels are not significantly reduced during AD, thus, a similar influent and effluent concentration should be expected. Dissolved and total orthophosphate, hydrolysable phosphate, and total phosphorus (all forms) are measured following EPA Method 365.2 (EPA 1971).

Results from the TP test can help assess if additional treatment of the effluent to remove P is needed, or if adjustments to an existing nutrient management plan for the AD effluent are necessary. For more information on the issues related to nutrient overloading and the different ways to remove P from effluent, refer to WSU Extension Publication, *The Rationale for Recovery of Phosphorus and Nitrogen from Dairy Manure* (Yorgey et al. 2014).

Gas Composition

Gas samples can be easily collected during the AD process, and the biogas composition can be measured (Standard Method D1945-14; ASTM 2014). Typical dairy manure derived biogas composition is 50 to 60% CH_4 and 40 to 50% CO_2, with low levels of other gases including water vapor, H_2S, oxygen (O_2), and nitrogen (N_2). An industry trend is to use online gas monitoring for both gas composition and flow rate. Variations in gas composition and flow rate may inform operators of potential problems with the digestion process. Software programs translate the information so it can be correlated with electrical production and carbon credits.

Pesticides, Pharmaceuticals, and Hormones

The AD process has the potential to reduce non-persistent pesticides, pharmaceuticals (including antibiotics) and endocrine disrupting hormones (Celis et al. 2008). However, persistent compounds can remain in the effluent. If this occurs, further treatment steps (e.g., **nutrient recovery** and composting) can be used to partially or fully remove/degrade these biologically active contaminants prior to land applying AD effluent (Kupper et al. 2008). The potential for these compounds to inhibit biogas production (Figure 4) and their degradation rates during AD and additional effluent treatments can be tested using **bench-scale** laboratory tests. Full-scale samples can also be tested. Methods used to analyze these contaminants are EPA Methods 1699 (EPA 2007a), 1694 (EPA 2007b), and 1698 (EPA 2007c).

Pathogens

The AD process has the potential to reduce potential pathogens including common indicator species such as **fecal coliform**. As a result, AD effluents may have lower pathogen concentrations than raw waste. As with composting, time and temperature play an important role in the degree of pathogen and indicator pathogen reduction. For example, the complete inactivation of *E. coli* is observed during AD at 52.5°C.

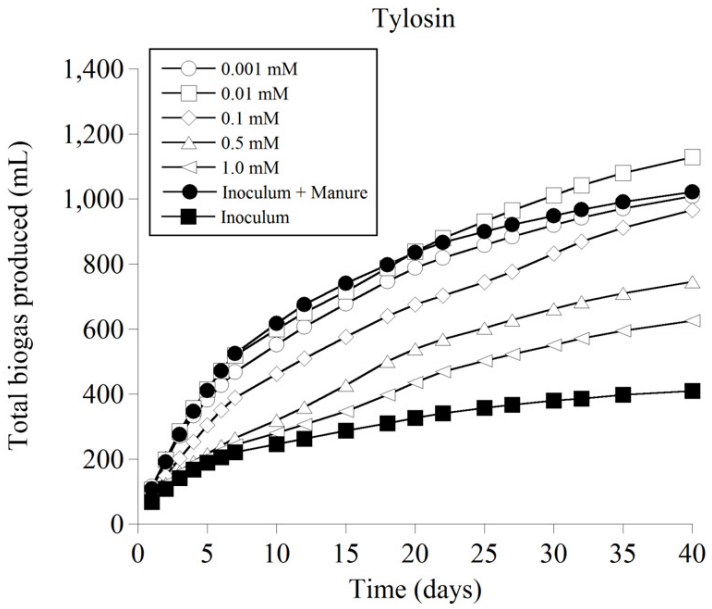

Figure 4. Total biogas production during a bench-scale inhibition study. High concentrations of the antibiotic tylosin inhibited biogas production. From Mitchell et al. (2013).

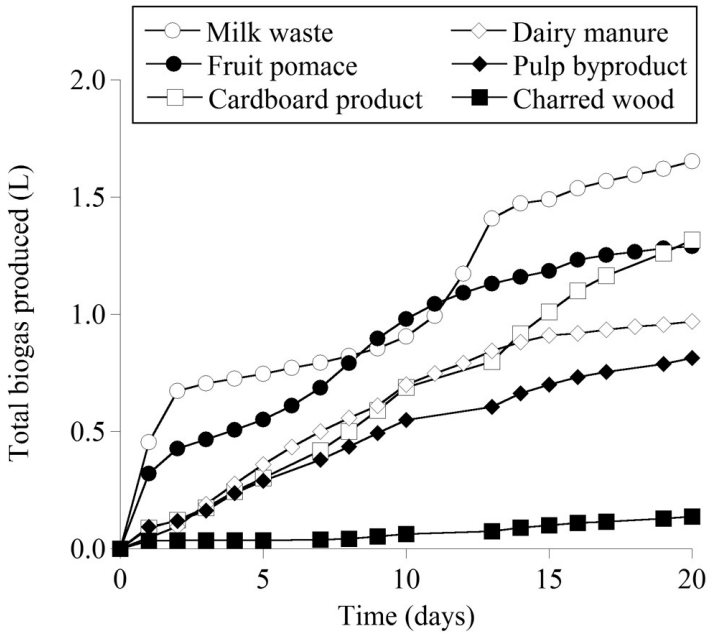

Figure 5. Total biogas production during BMP tests from various substrates. Ma and Frear, unpublished data.

However, at mesophilic temperatures (37°C), complete inactivation does not occur although levels are decreased (Pandey and Soupir 2011). Fecal coliforms are quantified by following EPA Method 1680 (EPA 2010a) and 1681 (EPA 2006) and methods are also described in *Standard Methods for the Examination of Water and Wastewater* (APHA 2012).

Process Stability Evaluations

Biochemical Methane Potential (BMP)

The **biochemical methane potential** test is a bench-scale **batch test** that evaluates biogas and CH_4 production during AD. This test is often used by industry during the design phase to predict total biogas output, allowing for correct sizing of engines and estimation of potential revenue. The BMP method is described in ISO Method 11734 (ISO 1995). During this test, biogas generated over time steadily increases for approximately 7 to10 days and then slows down until ultimate production is achieved (Figure 5). Examples of BMP results for different substrates are shown in Figure 5.

While cumulative biogas/methane production is a typical output of BMP studies, the raw data can also be used to determine the total biogas produced per gram of VS added to the BMP bottle (Figure 6A) and the total biogas produced per gram of wet material added to the BMP bottle (Figure 6B). It is important that BMP data reports include these multiple results.

For example, milk waste had the most biogas produced per gram of VS, but cardboard product had the most biogas produced per gram of wet material, followed by fruit pomace, milk waste, dairy manure, pulp byproduct, and charred wood (Figure 6A and 6B)—facts that would be of great economic importance to developers.

Anaerobic Toxicity Assays (ATA)

Anaerobic toxicity assays determine whether, and at what concentration, a substrate decreases biogas production. Excessive organic loading rates or high concentrations of toxins (e.g., NH_3) can inhibit the AD system. Anaerobic digesters practicing **co-digestion** use ATAs to determine if the various waste materials they receive could inhibit their digester.

ATAs are a variation of the BMP test. Varying amounts of the substrate or toxin are tested, and biogas is measured for 1 to 5 days. Then, the **inhibition factor** is calculated (ISO Method 13641; ISO 2003a; ISO 2003b):

$$I = (1 - (CH_4\ volume_{test}/CH_4\ volume_{control})) \times 100$$

ATA results displayed as inhibition factors quantitatively detail the impact that a substrate has on biogas production (Figure 7). In the Figure 7 example, > 7% volumetric loading of substrate 2 caused inhibition, informing digester operators regarding the limits and risks of using this particular substrate. However, > 13% volumetric loading of substrate 1 led to an increase in biogas production.

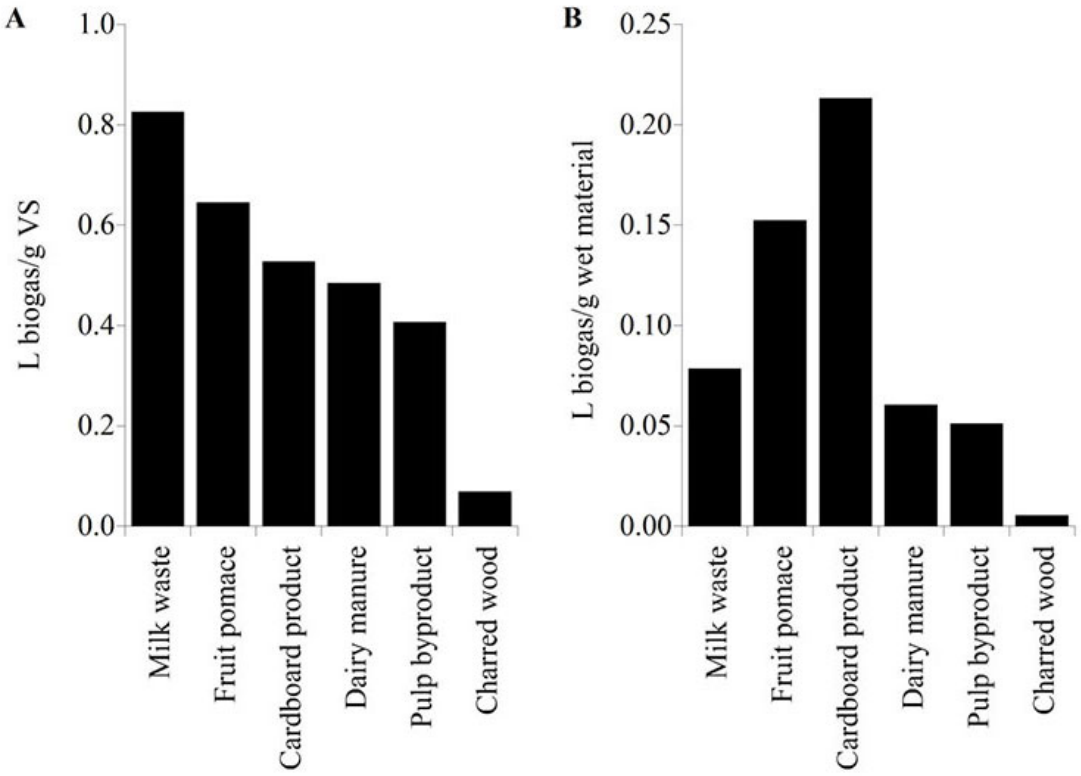

Figure 6a. Liters of biogas produced after 20 d of AD per g VS added to the BMP bottle. Ma and Frear, unpublished data. Figure 6b. Liters of biogas produced after 20 d of AD per g wet material added to the BMP bottle. Ma and Frear, unpublished data.

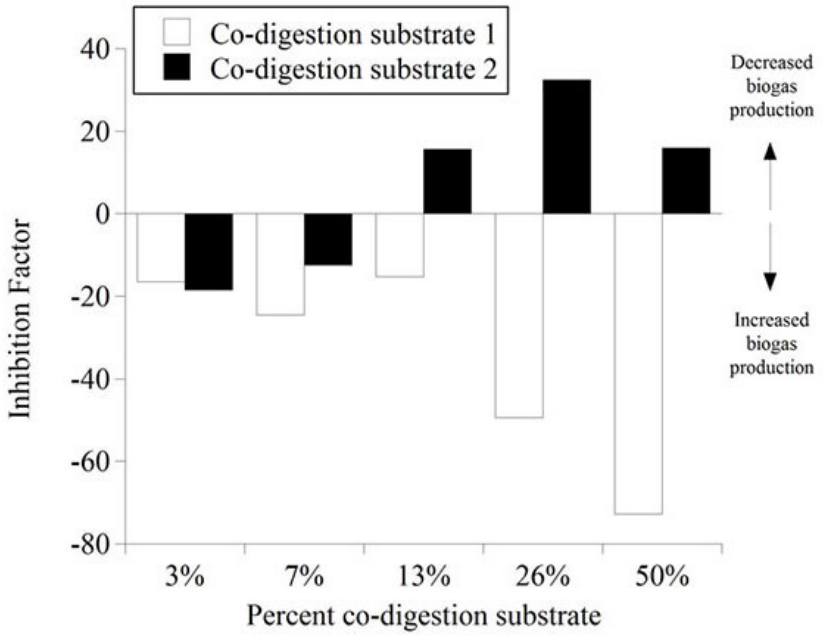

Figure 7. Inhibition factors from ATA tests that used different volumetric loading rates of two co-digestion substrates. The two co-digestion substrates were different forms of milk processing waste. Ma and Frear, unpublished data.

Microbial Population

Microbial populations are well characterized for municipal AD and manure AD reactors operating at 35 to 37°C (Figure 8). The two major groups of methanogens are Methanomicrobiaceae and Methanosaetaceae from the archaea domain. A current research endeavor is to elucidate microbial population shifts during anaerobic digestion with various substrates. Research questions actively being studied include the following: How does the dominant population present at 37°C compare to the dominant population present at 55°C? Does the reactor type change microbial populations? How does co-digestion shift microbial populations? This knowledge may lead to insight into acclimated inoculum for different substrates and types of reactors.

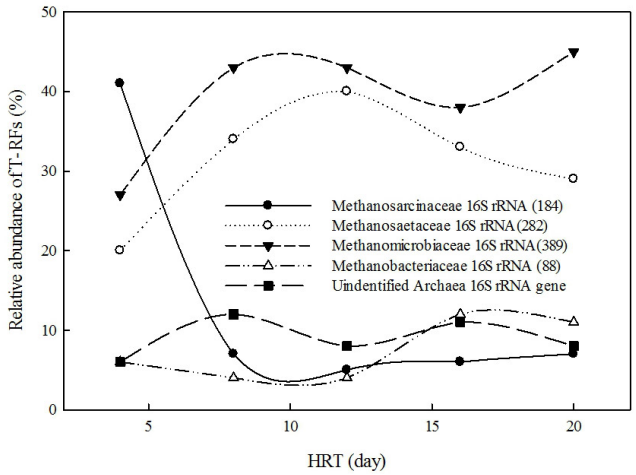

Figure 8. Relative abundance of the archaea 16S rRNA gene fragments retrieved from the biomass in an anaerobic sequential batch reactor. The length of T-RFs in base pairs (bp) is indicated in parenthesis. Modified from Ma et al. (2013b).

Anaerobic Digestion Optimization through Modeling

Modeling the AD process can help optimize process conditions for microbial growth rates, which in turn can improve biogas production. Simulating a full-scale AD reactor is generally less expensive than testing process changes physically. One of the most well developed and frequently used models for AD is the **Anaerobic Digestion Model 1** (ADM1; Batstone et al. 2002). Biochemical and physico-chemical reactions are the basis of this generalized AD model. Physical AD components can be modeled using other programs to optimize operating parameters, such as mixing (Figure 9).

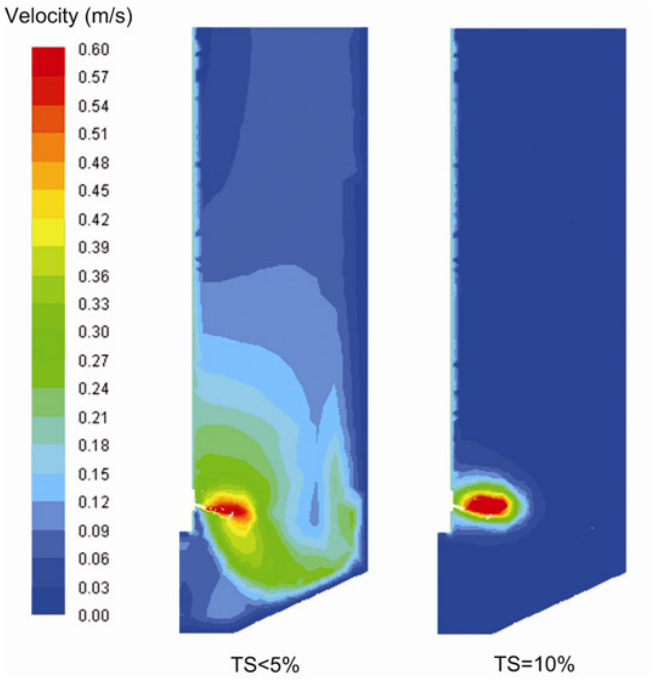

Figure 9. Liquid velocity in a high solids AD reactor using mechanical mixing. Increasing liquid velocity indicates more effective mixing. From Yu et al. (2011).

Summary

The number and size of anaerobic digestion operations in the US is growing due to the many positive environmental and economic qualities this technology can provide. Anaerobic digestion is a complex microbial process. Therefore, it is critical to maintain constant process conditions in order to sustain process optimization and avoid reactor upsets. Laboratory techniques are necessary to evaluate the AD influent, effluent, and process stability. In addition, modeling is an economical solution for improving and optimizing AD technology.

Moving Forward

Anaerobic digestion technologies continue to advance, with active research and development in both the AD industry and university settings. Research institutions are contributing to existing and proposed AD projects with improved design components and solutions to observed challenges. Ongoing research areas include improving the reactor design, mixing operations, and pre-treatment strategies to improve AD performance, as well as post-treatment strategies to improve effluent qualities and further enhance developed products.

Acknowledgements

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Glossary

A

Acetic acid – small volatile fatty acid. It has one carbon chain attached to the carboxylic acid group.
Acetogenesis – anaerobic microbial metabolic process that produces acetic acid, hydrogen, and carbon dioxide from volatile fatty acids. The microbes are called acetogens.
Acidogenesis – anaerobic microbial metabolic process that produces volatile fatty acids, acetic acid, hydrogen, and carbon dioxide from amino acids, sugars, and fatty acids. The microbes are called acidogens.
Alkalinity – the capacity of a material to neutralize acids.
Ammonia inhibition – decreased performance due to a presumed over-concentration of ammonia in the digester.
Anaerobic – an environment that does not have oxygen.
Anaerobic digester – the facility and reactor where anaerobic digestion occurs.
Anaerobic digestion (AD) – the microbial metabolic process that occurs in environments void of oxygen.
Anaerobic digestion model 1 (ADM1) – a generic model and common platform for dynamic simulations of a variety of anaerobic processes. It was produced by the IWA Task Group for Mathematical Modeling of Anaerobic Digestion Processes.
Anaerobic microorganism – microorganism in the bacteria or archaea domain that lives in oxygen free environments.
Anaerobic toxicity assays (ATAs) – AD batch test procedures used to measure decreased biogas production from different substrates or substrate loading rates.

B

Batch test – a setup that uses one addition of inputs for the duration of the reaction.
Bench-scale – a small laboratory-scale setup.
Biochemical oxygen demand (BOD) – an indirect measure of the amount of organic carbon in a material. It is based on oxygen depletion in a contained aqueous reaction from microorganisms consuming biodegradable material.
Biochemical methane potential (BMP) – an AD batch test procedure used to measure the volume of biogas/methane produced from a known quantity of feedstock.
Biodegradable – a characteristic that describes organic molecules that decompose/biodegrade.
Bioenergy – renewable energy made from biomass.
Biofertilizers – fertilizers deriving from a biological process or biomass.
Biogas – gas emitted from AD. It predominately contains methane and carbon dioxide with trace gases including hydrogen sulfide and water vapor.
Biogas scrubbing – technology used to remove carbon dioxide, hydrogen sulfide, and water vapor from biogas to obtain a higher purity methane product.
Biomass – living or recently living biological material.
Biomethane – methane produced from AD.

C

Carbon dioxide – a non-combustible gas with the chemical formula CO2. During AD, it is produced after acidogenesis, acetogenesis, and methanogenesis.
Chemical oxygen demand (COD) – an indirect measure of organic carbon in a material. It measures both biodegradable and recalcitrant organic molecules.
Co-digestion – anaerobic digestion processes incorporating off-farm organic feedstocks (e.g., fats, oils, greases, or food waste) with a main feedstock (e.g., dairy manure). It is a practice of purposefully feeding the digester with multiple forms of organic material to gain yield, economic benefits, and process improvements.
Combined heat and power (CHP) – technology that converts biogas into electricity and heat.
Complete mixed reactor (CMR) – reactor design that is made up of one large cylindrical tank that is continuously mixed using gas injections (biogas for AD) or mechanical mixers. It is also called continuous mixed reactor (CMR), complete/continuous stirred tank reactor (CSTR), and complete/continuous mixed flow reactor (CMFR).
Compressed natural gas (CNG) – for AD, it is biogas that has been purified through removal of carbon dioxide, hydrogen sulfide and other contaminants, and then the methane is compressed for vehicle use.
Concentrated animal feeding operations (CAFOs) – small, medium, or large agricultural operations where animals are kept and raised in confined situations for more than 45 days in a 12-month period in a pen with no grass or other vegetation during the normal growing season and also meets the criteria outlined in the “Regulatory Definitions of Large CAFOS, Medium CAFOS, and Small CAFOs” (EPA 2014b).
Covered lagoon (CL) – anaerobic digester reactor design that is made up of a lined pit and a flexible plastic cover.

E

Effluents – the end products from a process. They can be in the solid, liquid, or gaseous form.

F

Fatty acids – long carbon chain carboxylic acids; volatile fatty acids have less than 8 carbon units, medium chain fatty acids have 8 to 16 carbon units, and long chain fatty acids have more than 16 carbon units.
Fecal coliform – indicator pathogens. They are measured to estimate pathogen levels in manure and effluents.
Feedstock – the organic waste stream that can be used in anaerobic digesters, also called substrate.
Fiber – following cattle manure AD, it is the dewatered solids material.
Fixed film anaerobic digester – anaerobic digester reactor design that consists of a tank filled with inert media on which a consortium of bacteria attach and grow as a biofilm.
Fixed solids (FS) – the inorganic fraction of a material which is non-volatile and non-combustible (e.g., sand, silt, clay).

G

Greenhouse gas (GHG) – gas that contributes to the greenhouse effect, such as carbon dioxide, methane, and nitrous oxide.

H

Heterogeneous – a material containing more than one unevenly dispersed component.
Hydraulic retention time (HRT) – for AD, it is a measure of the average length of time a feedstock remains within a reactor. It is defined as the volume of the reactor divided by the influent flow rate.
Hydrogen gas – a combustible gas with the chemical formula H2. During AD, it is produced from acidogenesis and acetogenesis.
Hydrogen sulfide – a gas with the chemical formula H2S. It is corrosive to engine components and hazardous to human health; a small amount can be produced during AD.
Hydrolysis – a bond breaking reaction that converts molecules with hydrolytically labile functional groups into smaller molecules. During AD, proteins, carbohydrates, and lipid polymers are hydrolyzed into monomers (i.e., amino acids, sugars, and fatty acids).

I

Influent – the materials that enter a system. AD influent consists of feedstock, anaerobic microorganisms, and dilution water.
Inhibition factor – a number representing the degree of inhibition from a substrate or toxin, based on biogas production during the ATA procedure.

L

Lagoons – reactors that are made up of a lined pit that is open to the atmosphere. The lagoon remains anaerobic below the surface of the liquid when no mixing is used.
Liquefied natural gas (LNG) – for AD, it is biogas that has been purified through removal of carbon dioxide, hydrogen sulfide and other contaminants, and then the methane is liquefied for ease of storage and transport.

M

Manure management – mandatory plan to mitigate water, soil, and air quality problems when high volumes of animal manures are generated at a facility. Typically these plans include anaerobic digestion and aerobic composting techniques.
Methane – a combustible gas with chemical formula CH4. During AD, it is produced from the methanogenesis step and it is used to produce energy (e.g., electricity, heat, renewable natural gas).
Methanogenesis – anaerobic microbial metabolic process that produces methane from reactions using acetic acid, hydrogen, and carbon dioxide. The microbes are called methanogens.
Methanogens – methane producing microbes from the Archaea domain.
Mesophilic – temperature conditions of 25–40°C, typically 35°C for mesophilic AD.
Mixed plug flow reactor (MPFR) – horizontal plug flow reactor design that incorporates progressive steps of narrow vertical mixing using gas injections (biogas for AD) throughout the length of the long rectangular channel.
Modeling – the use of computer software programs to simulate a process where the user can observe changes to the process outputs when inputs or process conditions are changed.

N

Nutrient recovery (NR) – processes that recover nutrients, most commonly phosphorus and nitrogen, from wastes. Some nutrient recovery processes are appropriate to untreated forms of wastewater, while others are appropriate for combination with anaerobic digestion. Many nutrient recovery processes generate nutrients in a recoverable form that can be used as fertilizer.

O

Organic loading rate (OLR) – the amount of soluble and particulate organic matter that is added to a reactor.
Organic waste – waste that is comprised of organic compounds.

P

pH – a measurement used to determine whether a substance is acidic or alkaline and to what degree.
pH buffer capacity – a property that describes how well a material maintains a certain pH or pH range.
Plug flow reactor (PFR) – horizontal reactor design that uses the hydraulic pressure of the influent to move the feedstock through the reactor and out as treated effluent.

R

Reactor – a contained vessel where reactions take place. For AD, biological reactions drive the process although chemical/thermal reactions are also important.
Recalcitrant – a characteristic that describes organic molecules that do not degrade during natural decomposition processes.
Renewable natural gas (RNG) – for AD, it is biogas that has been purified through removal of carbon dioxide, hydrogen sulfide and other contaminants. It is an upgraded methane product that can be used for compressed natural gas, liquefied natural gas, pipeline quality gas, fuel cells, etc.
Ripley Ratio – ratio of volatile acids to total alkalinity. It is a means to estimate alkalinity and buffer capacity.

S

Sequential batch reactor (SBR) – reactor design that is made up of a tank in which all of treatment stages (feeding, reaction, settling, discharge) takes place in series.
Soluble chemical oxygen demand (SCOD) – an indirect measure of organic carbon from a filtered sample. It measures both biodegradable and recalcitrant organic molecules.
Substrate – the organic waste stream that can be used in anaerobic digesters, also called feedstock. This terminology is predominantly used when referring to co-digestion.

T

Thermophilic – temperature conditions of 40-80°C, typically 55°C for thermophilic AD.
Total ammonia nitrogen (TAN) – the amount of ammonia and ammonium.
Total Kjeldahl nitrogen (TKN) – the amount of organic nitrogen, ammonia, and ammonium.
Total phosphorus (TP) – the amount of all forms of phosphorus.
Total solids (TS) – the total dry matter of a material. The total dry matter is made up of both organic (i.e., VS) and inorganic (i.e., FS) matter.

U

Up flow anaerobic sludge-blanket (UASB) – anaerobic digester reactor design that uses an up-flow regime to develop dense granular sludge, which allows for high volumetric loadings.

V

Volatile fatty acids (VFAs) – short carbon chain carboxylic acids.
Volatile solids (VS) – it is considered the organic fraction of a material. It includes both easily digestible organic carbon and recalcitrant organic carbon. It could also include some inorganic compounds like salt minerals that vaporize at 550°C, thus VS may not be an accurate measure of organic content for some feedstocks.

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