Anaerobic Digesters: Designs

Fact Sheet FS-xxx 2013
Currently Under Review

At their most basic, anaerobic digesters are airtight, oxygen-free containers used to generate biogas from the microbial breakdown of organic wastes. They can be constructed from any number of different materials designed using many methods, but the simplest construction is a container filled with liquefied waste and closed to the external environment (Figure 1).

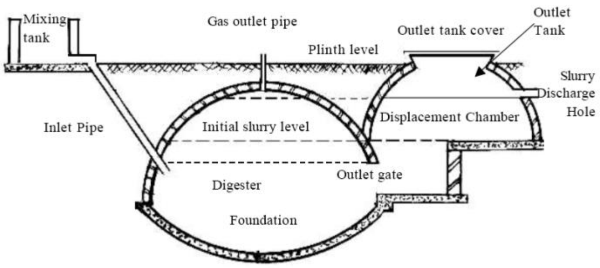

Figure 1. A typical Indian fixed-dome anaerobic digester. The system is closed, but air from the slurry discharge hole can still enter the digester. By filling the main chamber with waste up to the initial slurry level, even this small amount of air can't reach the majority of the waste, and the digester quickly becomes anaerobic, or oxygen free. (Diagram credit: Action for Food Program)[1]

When building a digester, the level of complexity required depends on factors such as climate, feedstock, desired treatment times, required pathogen destruction, planned biogas production, and available capital. The following is a summary of digester designs frequently seen in the cooler climates of the United States and Europe.

Complete Mix or Continuously Stirred Tank Reactors (CSTRs)

CSTR digesters are generally cylindrical containers made of fiberglass, steel, or reinforced concrete and may be built above ground or partially buried[2,3] (Figure 2).

Figure 2. A complete mix, or CSTR, digester. (Photo credit: Layne Christensen Company)

In all areas outside of the tropics, where ambient temperatures drop below the ideal levels for anaerobic digestion, CSTRs are usually insulated and the digestion chamber is heated with internal hot water piping and/or internal and external heat exchangers coupled to heat sources such as combined heat and power (CHP) electric generators[2–4]. CSTRs are most often designed for operation in mesophilic or thermophilic temperature ranges[2,3,5].

The contents of these digesters generally range from 2-5% solids by volume, although they are often used for both scraped and washed manure management systems[2,3]. As their name implies, CSTRs are constantly mixed via pumps, electric propellers, or pressurized biogas agitators in order to keep the solids portion of the waste in suspension and prevent it from settling (Figure 3).

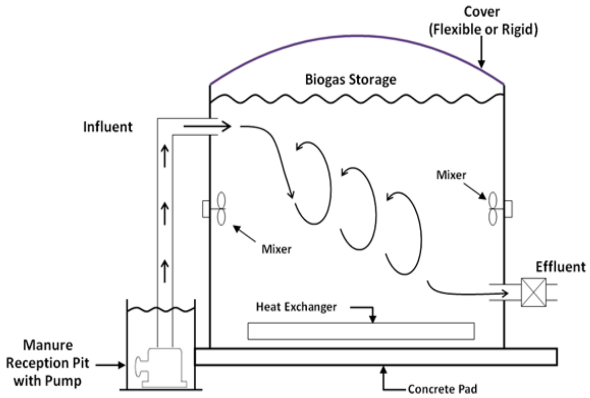

Figure 3. Mechanics of a CMTR. (Diagram credit: AgSTAR)

The waste is usually digested for 10-30 days (the hydraulic retention time, or HRT) before being pumped to a solids separator to remove the undigested material, such as bedding[2,3]. (When sand bedding is used, it will settle out in the digester; and therefore, must be separated prior to digestion[6,7].) The remaining stabilized waste is then pumped or gravity-fed to storage lagoons for later use as a crop fertilizer. Biogas generated during the process is captured under the airtight dome of the digester and may be scrubbed and used immediately for heating, electricity generation, vehicle fuel, or compressed for storage.

Plug Flow

Plug flow anaerobic digesters are most often constructed as buried, reinforced concrete, fiberglass, or steel tanks. As a rule, they are five times longer than they are wide and are covered with a gas-tight flexible geo-membrane material similar to a pond-liner[3,8] (Figure 4).

As in CSTRs, piped hot water and/or heat exchangers are combined with insulation to keep the digesters warm in colder climates[3]. Plug flow systems are also typically operated at mesophilic or thermophilic temperatures.

Figure 4. An operating plug flow digester. (Photo credit: AgSTAR)

Plug flow digesters are designed for high-solid waste streams (usually 10-15% total solids)[7] and are ideal for scraped manure management systems. As with most digestion systems, sand bedding must be settled out before being introduced to the digester[6,7]. In theory, waste enters the system as a plug, flowing into one end and progressively moving through the digester as new waste is introduced.

After the designed retention time – anywhere between 15 and 30 days[6,7] – the plug is forced out as effluent and drained to a holding lagoon. Although mixing is not theoretically required in plug flow systems, in practice, many designers and owners have found the need to agitate to avoid manure crusting and short-circuiting of the system. To that end, plug flow digesters may incorporate some of the stirring aspects of CSTR digester designs. Biogas quality from plug-flow digesters is comparable to that of other systems, and the gas may be used in all of the same ways.

Covered Lagoon

Covered lagoon digesters are often retrofits of existing manure lagoons and may be operated as a combined digester and waste storage lagoon or split into two or more single-function units[9,10]. They consist of a holding basin, often constructed using pond-liner materials, and a fixed or floating impermeable membrane cover. Covered lagoon digesters operate at ambient temperatures and, in colder climates, this can result in lower biogas production when compared to heated systems[11].

Figure 5. A covered lagoon digester in California. (Photo credit: KQED, 2007)

Covered lagoon digesters are designed for low solids waste streams (<2% total solids), and generally require separation of the solid constituents of the manure prior to digestion[7,11]. Waste is pumped or gravity-fed to the digester in a manner similar to most plug flow systems and, due to lower operating temperatures, planned HRTs range from 35 to 60 days[7,9,11].

Fixed Film

Fixed film digesters are constructed in much the same way as CSTR digesters, but with several key differences[12]. Most importantly, fixed film digesters are designed to house a non-degradable, high surface area material inside of the digester to serve as a growth media for the anaerobic microbes. Varying materials are employed – for example, the University of Florida's fixed film research digester uses sections of vertically stacked 3-inch corrugated plastic pipe[12] – but the fundamental purpose is to increase the density of the microbial population, leading to reduced HRTs and smaller digester volumes. As with CSTRs, these systems operate at mesophilic or thermophilic temperatures[7,13].

Figure 6. Fixed-film digester operating in Florida. (Photo credit: Ann C. Wilkie)

Similar to covered lagoon systems, fixed film digesters are designed for low solid waste streams (<2% total solids) and require sand-settling or screen separation of bedding prior to digestion[7]. The liquid waste is designed to move through and around the fixed media, and flows from either bottom to top (upflow) or top to bottom (downflow). HRTs range from 3-5 days, after which the waste and biogas are handled in the same fashion as other digestion systems[7,13].

Upflow Anaerobic Sludge Blanket (UASB)

Similar to fixed film digesters, UASBs are high-rate, wastewater treatment systems designed to reduce the necessary volume of the digester. UASB designs revolve around the upwelling of waste from an inlet at the bottom of the digestion chamber, which encourages the formation of layers of sludge and/or sludge granules consisting of waste, bacteria, and by-products of the microbial processes occurring in the digester[14–16] (Figure 7).

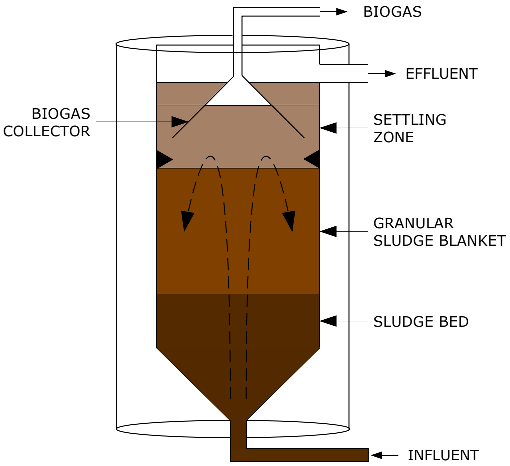

Figure 7. Typical UASB reactor and process design. The layered sludge and granules provide increased surface area for bacterial growth, thereby allowing for a combination of long solids retention times (SRTs) and short HRTs when the process is optimized. Similar to CSTRs and fixed film digesters, UASBs can operate in either mesophilic or thermophilic temperature regimes[14,17] and treat lower-strength, diluted wastes[16].

Cost

Digester capital costs vary greatly according to a number of variables including the required treatment capacity, local climate, desired operating temperature, type of waste stream, intended use of biogas, and many other factors unique to each farm. A brief compilation of capital costs per cow for dairy farms is provided in Table 1, including information on the state of operation for each system included.

Table 1. Average capital cost for anaerobic digesters on dairy farms in 2011 dollars

Digester Type	Ave. cost per cow	Ave. # cows	Electricity Generation	# Projects [Built, (Projected)]
Covered Lagoon[19]	$2,175	100	No	0, (1)
Covered Lagoon[18,19]	$844	495	Yes	1, (2)
Plug Flow[19]	$1,369	150	No	1, (2)
Plug Flow[19]	$2,224	120	Yes	1, (0)
Complete Mix[19]	$1,466	173	No	2, (1)
Complete Mix[19]	$1,963	180	Yes	2, (0)
Fixed Film[19]	$1,503	175	No	2, (0)
Fixed Film[18]	$1,184	625	Yes	0, (2)

Emerging Designs for Small-Scale Farms

Modified Taiwanese Plug-flow Bag Digesters

Taiwanese bag digesters are common throughout the world, but especially in Latin America, where they are often used to treat dairy and swine manure[20–22]. The mechanics of these digesters are very similar to traditional U.S. plug-flow designs, but their construction differs. Most Latin American bag digesters are directly buried in the ground, where the digester bag (often a PVC or polyurethane-based material) is attached to influent and effluent plumbing, inflated, and filled to capacity (Figure 8).

Figure 8. Typical Central American bag digester. (Photo credit: AIDG)

The University of Maryland has begun efforts to adapt this particular design to the temperate climates of the United States. Dual-walled, corrugated high-density polyethylene culverts are buried to provide insulation, and house typical Latin American bag digesters, with insulation and radiant hot water piping added to further maintain heat (Figure 9).

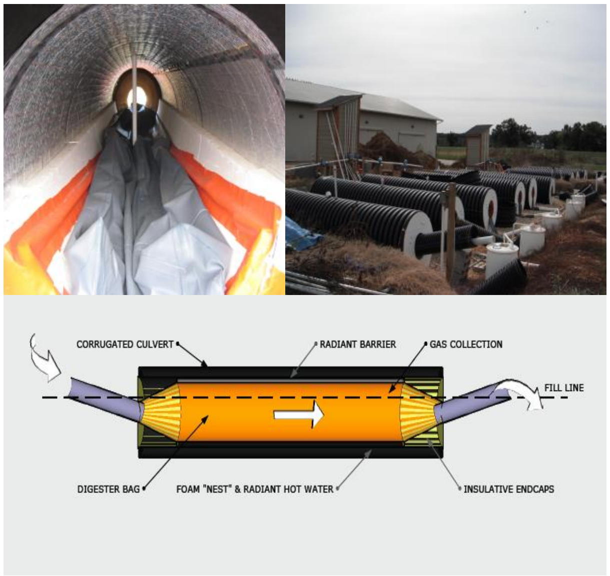

Figure 9. The University of Maryland's modified plug-flow digesters. Upper left: The UMD design utilizes external radiant hot water heating (orange) to warm the digester, as well as a bed of foam insulation (white), a radiant barrier (silver), and foam end-caps to retain heat. Upper right: Digester site, showing digesters (black) and recirculation basins (white). Bottom: As with most plug-flow systems, manure enters the digester via gravity flow, displacing the digester contents and forcing digested manure out the back; a seal is maintained by the common level of manure at the fill line.

The plug-flow digesters are designed for high-solids waste streams (10-15%), but operate on pre-separated liquid manure, as well. Dairy manure is pre-heated using biogas and gravity-fed to the digesters in a manner similar to other plug-flow designs, where it is maintained at mesophilic temperatures. Periodic, pumped recirculation of the waste from the back end to the front aids in maintaining a healthy microbial community throughout the digester. Effluent and biogas are handled in a manner identical to standard digestion systems.

As an alternative to biogas-generated hot water for digester heating, solar hot water has been used in some systems. No biogas production values from these systems are currently available, so their viability is still unknown.

Modified Fixed-Dome Digesters

Fixed dome digesters may be the most ubiquitous digester design throughout the world, especially in southern Asia, where over thirty million digesters are currently operating[20]. In tropical regions, most fixed-dome digesters are built from mortar and brick, plastic, or fiberglass and are gravity fed a liquid waste substrate. Nearly all designs approximate that seen in Figures 1 and 10.

Figure 10. A fixed-dome digester under construction in Africa. (Photo credit: Bustler)

In the United States, fixed-dome digesters are currently being researched to explore their suitability for temperate climates. The Ohio State University has designed a pilot-scale, insulated fixed-dome digester for the treatment of dairy manure. A buried, spray-foam insulated, polyethylene storage tank retrofitted with influent and effluent plumbing[23] accepts manure consisting of up to 10% total solids (Figure 11).

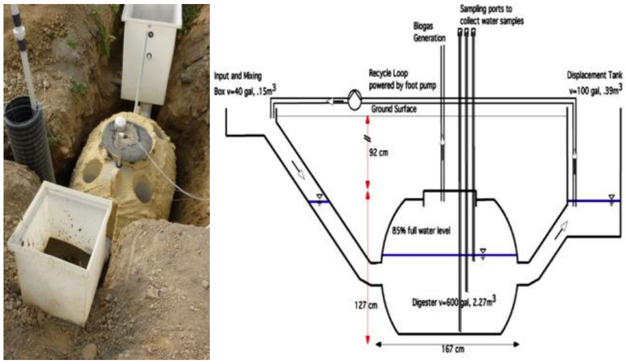

Figure 11. Left: The OSU modified fixed-dome digester. Right: A schematic representing the digester's operation. (Photo credit: Jay Martin, OSU)

Some systems have explored the idea of direct burial beneath compost piles as a means of maintaining warm digester temperatures[24]. This alternative might be especially attractive in systems designed for pre-separation of the solid constituents in manure, as the solids would provide a viable composting product for heat. Although a promising possibility, at present there is not enough data available to prove the efficacy of the design.

More Information

More information can be found by contacting your local agricultural extension agent or by visiting the Cooperative Extension System website at http://www.extension.org/ag_energy.

Additional contacts

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This publication, Anaerobic Digesters: Designs (FS-xxxx) , is a series of publications of the University of Maryland Extension and the Department of Environmental Science and Technology. The information presented has met UME peer review standards, including internal and external technical review. For more information on related publications and programs, visit http://www.enst.umd.edu/. Please visit http://extension.umd.edu/ to find out more about Extension programs in Maryland.

Issued in furtherance of Cooperative Extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, University of Maryland, College Park, and local governments. Cheng-i Wei, Director of University of Maryland Extension.