Section 4
Technology Options

Market Opportunities for Anaerobic Digestion of Livestock and Agro-Industrial Waste in India

Prepared for:

The Global Methane Initiative
February 2020

4. Technology Options

This section of the market opportunities assessment identifies current anaerobic digester technologies used in India. It summarizes key attributes of anaerobic digesters and identifies small-scale digester technologies used at a household or farm level, followed by medium- and large-scale digester technologies used on a commercial scale. It helps inform project developers and policymakers about the process, types of feedstock, and the scale at which each of these technologies is currently being implemented. Other AD technologies are available and in use in other countries, but are not currently appropriate for use in India. This section helps technology providers and project developers understand the technology landscape in India so they can consider adapting these alternative technologies to the Indian context.

A variety of anaerobic digestion (AD) technologies are in use in India. Technology designs vary, based on a number of attributes, including feedstock solids content, process stages, operation mode, and operation temperature, as shown in Table 17 and described below. Understanding these different attributes can help project implementers choose the right technology type to meet their needs.

Table 17. Attributes of AD Systems

Feedstock Solids Content	Process Stages	Operation Mode	Operation Temperature
▪ Wet ▪ Dry	▪ Single ▪ Multiple	▪ Batch ▪ Semi-continuous ▪ Continuous	▪ Thermophilic ▪ Mesophilic

- *Feedstock solids content:* AD systems are classified as high solids (“dry”) and low solids (“wet”) technologies based on the feedstock they process. Dry feedstock typically refers to a waste product with more than 15 percent solids content. Dry AD systems process materials that can be stacked and require little or no preprocessing of materials. These systems usually take feedstock from commingled yard and food waste. Other than removing contamination and properly mixing the material, no additional preprocessing is needed. Feedstock for wet AD systems must be preprocessed (e.g., have liquid added) to create a pumpable slurry for easy movement through the system. These systems usually process sewage sludge, manure, food processing industry wastewater, and clean food waste that is shredded and pre-processed to a slurry stage.
- *Process stages:* AD systems are single- or multi-stage systems based on the number of digester tanks in the series where the reactions take place. Two-stage systems are common, but some configurations include more tanks.
- *Operation mode:* AD systems are classified as batch, semi-continuous, or continuous based on how the feedstock material is introduced into the digester.
  - In batch systems, the digester is filled to its capacity with no mixing or additional feedstock until the processing time is completed. Feedstock is left in the reactor for the system’s designed retention time. These are the most robust AD systems with the highest tolerance for contamination and no significant feedstock preprocessing. Batch processing is used both in AD systems that process low-solid content feedstock such as manure and sludge and high-solid content feedstock such as the organic fraction of the municipal solid waste (MSW; usually a mix of food and yard waste).
  - In semi-continuous systems, a certain amount of feedstock is introduced into the reactor on a periodic basis (e.g., daily), while the same amount of digestate is removed from the effluent end of the digester. These AD systems may be used both to process low-solid content waste such as manure and high-solid content materials such as food and yard waste.
  - Continuous reactors are systems where the inflow of feedstock and the outflow of digestate is continuous. The flow rates are adjusted to allow for the necessary retention time for optimal rate of feedstock digestion. All continuous reactors need pumpable low-solid content feedstock with less than 20 percent total solid content. The feedstock needs to be in a homogeneous slurry form that is free from contamination so that it does not cause mechanical problems. These complex systems

require highly skilled operators and carefully chosen and prepared feedstock. Continuous reactors are suitable for wastewater treatment plant sludge, wastewater from the food processing industry, and diluted manure.

- *Operation temperature:* AD systems can be mesophilic or thermophilic based on operating temperatures. Mesophilic systems operate between 68 and 113 degrees F (20–45 degrees C) and thermophilic systems operate between 113 and 140 degrees F (45–60 degrees C). Mesophilic digestion is typically more stable and does not require heating, although gas yields are lower as the temperature decreases. Thermophilic digestion generally allows for reduced retention times, higher gas yields, and higher loading rates.

Understanding feedstock solids content, operation mode, processes stages, and process temperature is key to selecting the correct digester to use as different processers will be appropriate for different biogas projects. Using a digester that is suited to a project allows a user to more effectively and efficiently process waste and produce optimal quantities of biogas.

4.1 Small-Scale AD Technologies

Small-scale AD systems described here have a capacity of 130 m^3 in digester volume, or up to 7,000 m^3 of material processed per year. The main feedstocks typically consist of animal manure, human waste, crop waste, and/or food waste. These systems are often decentralized and serve a single farm or a household, and are usually privately owned by a household or farmer. The most commonly used simple and low-technology small-scale AD systems include fixed dome reactors, floating drum reactors, and bag digesters. Continuously mixed systems (described in Section 1.2.1 on medium and large AD systems) have been designed on a small-scale and used.

Fixed Dome Digesters

Fixed dome digesters (shown in Figure 17 and Figure 18) may be constructed of either concrete, bricks and mortar, or a combination of both. They are the most commonly used digesters for household biogas plants in India. It is estimated that around 80 percent of the 5 million digesters in India are fixed domes. These digesters are shaped like an igloo and built underground. Waste is fed into the digester through an inlet, often with a mixing pit located at the inlet. The waste decomposes in the body of the digester and the produced gas is collected at the top of the digester. The digestate slurry is displaced into a tank by the pressure of the produced gas.

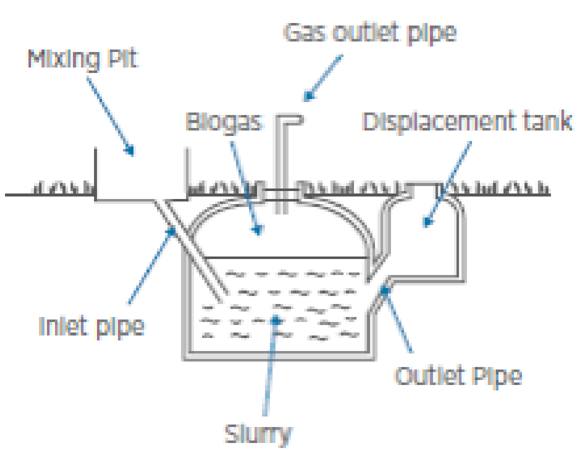

Figure 17. Fixed Dome Digester Diagram

Source: IRENA, 2017.

Figure 18. Fixed Dome Digester During Construction

Source: Mantopi Lebofa, 2006.

Deenbandhu digesters are a common type of fixed dome digesters in India. Deenbandhu digesters have a slightly different shape than other fixed dome digesters, as shown in Figure 19 and Figure 20. They are popular in India due to their ease of construction, low cost, and small footprint.

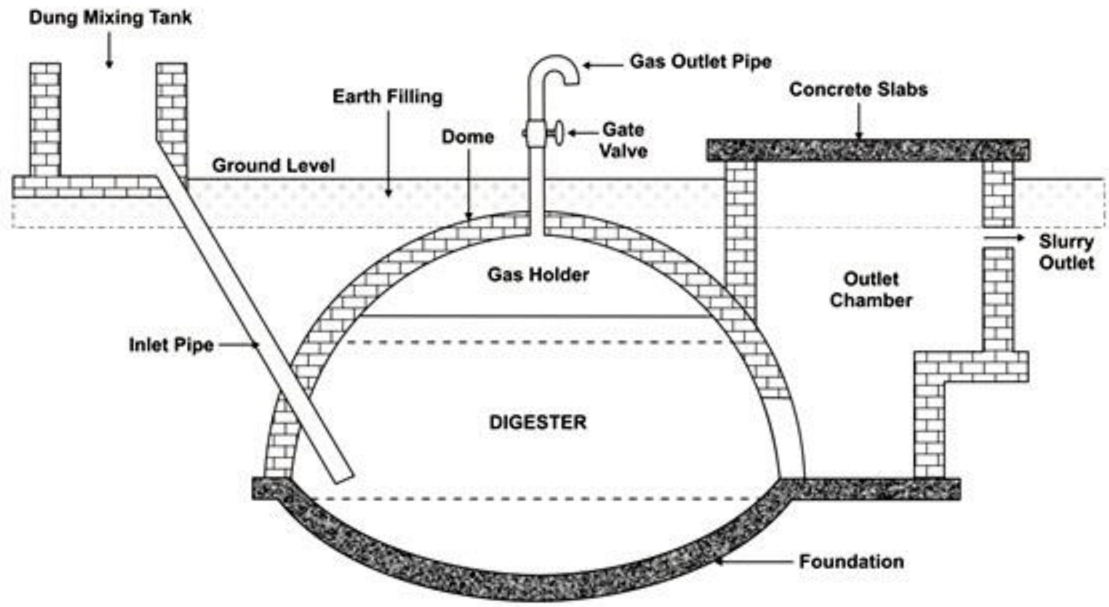

Figure 19. Deenbandhu Digester Diagram

Source: Singh, 2014.

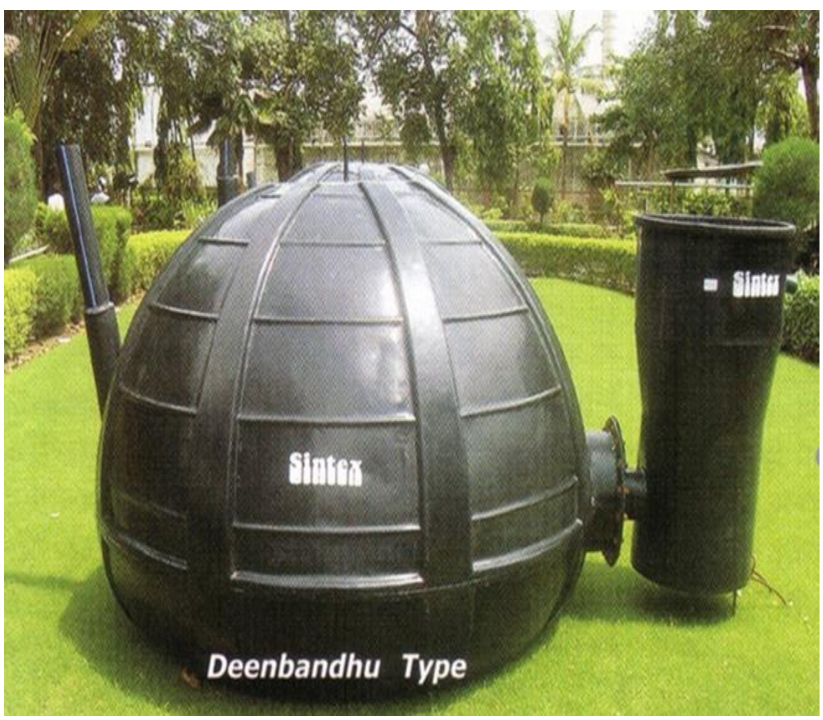

Figure 20. Deenbandhu Digester

Source: Sintex

Floating Drum Digester

The floating drum system (shown in Figure 21 and Figure 22) was originally developed in India by the Khadi and Village Industries Commission (KVIC), and consists of an underground reactor in brick or concrete and a stainless steel gas holder that floats on the top (the floating drum) along a central guide. The metal floating dome is used as gas holder, which is usually designed to store only a portion of the daily gas production as the produced gas is consumed throughout the day.

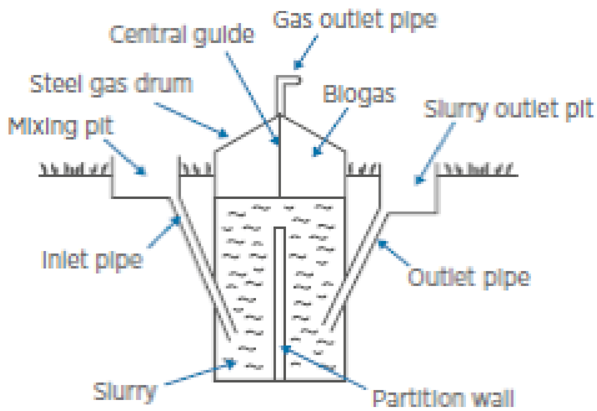

Figure 21. Diagram of a Floating Drum System

Source: IRENA, 2017

Figure 22. Floating Drum Digester

Source: McKay Savage, 2008

Floating drum systems have a robust design that are easy to construct from locally available materials. The digester can be constructed onsite and has a very long lifetime; but the stainless steel drum has to be fabricated at a specialized facility, and requires regular maintenance as it is subject to corrosion. The challenges associated with these systems are their higher costs and maintenance requirements when compared to a fixed dome system.

The National Biogas Program has promoted both the fixed dome and floating drum digesters to meet cooking fuel requirements of individual homes since 1982, and over 4 million household plants have been built in India.

4.2 Medium/Large-Scale AD Technologies

Medium and large-scale AD systems have a capacity larger than 130 m^3 in digester volume, or process more than 7,000 m^3 of material per year. Medium and large AD systems use a variety of feedstocks, including manure; sludge from wastewater treatment plants; organic fraction of MSW; food processing waste; fats, oils, and greases; and combinations of any of the above. Facilities of this size are considered commercial scale and may be centralized or decentralized.

Commercial-scale AD systems have been successfully implemented worldwide for more than a century. The largest number of commercial AD systems are in Europe, with 17,662 installations operating across Europe in 2016 (European Biogas Association, 2017). The combined number of AD systems generating biogas in the United States was around 1,500 in 2015, including wastewater treatment plants, farm-scale systems, and food waste systems (American Biogas Council, 2018). In India, over 450 biogas plants with a capacity of over 750 MWeq have been built for the recovery of biogas from wastes and effluents generated by various industry segments including distilleries, starch mills, and the food processing industry. In addition, many biogas plants of medium to large capacities have also been installed for producing biogas from cattle manure in rural areas of India. Medium-scale projects (around 100 m^3 to 500 m^3 biogas per day capacity plants) may also be based on the fixed drum and floating gas holder type digesters described in the previous subsection.

Completely Mixed Digester

Completely mixed digesters (shown in Figure 23 and Figure 24) are vertical cylindrical tanks made of concrete or steel and covered with an impermeable gas-collecting cover. Also known as Continuously Stirred Tank Reactors (CSTRs), these systems are the most popular digester option for large-scale applications. They keep heterogeneous feedstocks in a homogeneous form, and also improve the contact of the feedstock (heterogeneous and liquid effluents) with micro-organisms to increase digester efficiencies. Distillery effluents, poultry droppings, cattle manure, agro residues, and food processing industry wastes and residues are some of the feedstocks for which CSTRs are being deployed at large capacities.

Usually built above ground, they can be operated as mesophilic or thermophilic reactors. Processed material is continuously stirred by motor, pump, or recirculation of the produced biogas. Completely mixed digesters work best with feedstock such as manure diluted with water (e.g., milking center wastewater), preprocessed and diluted food waste, or food waste processing wastewater. Feedstock should be in slurry form and free of inorganic contaminants. These systems can process all types of feedstock (including codigestion of different feedstock), and high conversion efficiencies can be obtained. Depending on the operation temperature, the retention time can be as low as 15 days and these systems can operate in any climate as heating the digester content is more economically feasible due to high conversion efficiencies.

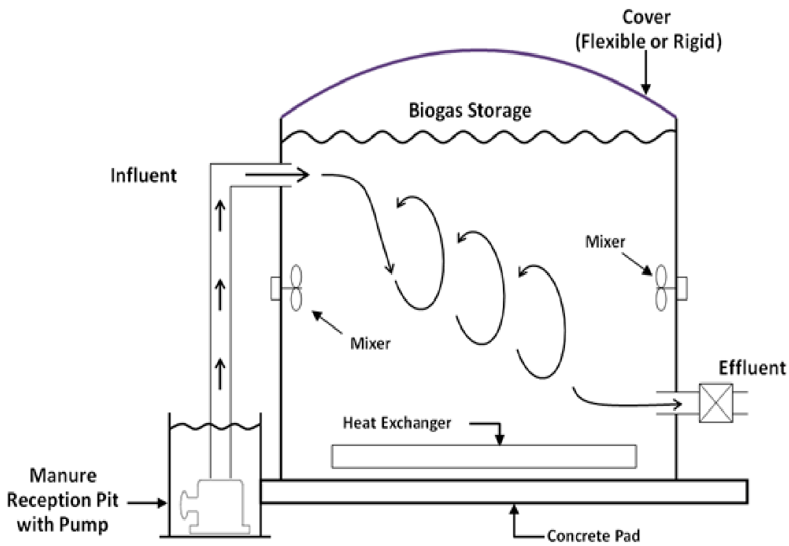

Figure 23. Diagram of Completely Mixed Digester

Figure 24. Completely Mixed Digester

Covered Lagoon

Covered lagoons are simple, low-technology, in-ground systems. The bottom of the reactor is lined and the lagoon is covered with an impermeable gas-collecting cover. The contents are typically not mixed and are usually connected to an effluent cell that is aerobic for collection of the processed material. Covered lagoons work best with manure handled via flush or pit recharge collection systems in warmer climates as covered lagoons are not typically heated. The feedstock these systems can handle has a low solid content (0.5 to 3.0 percent) and have relatively long retention times of 40 to 60 days. While costs will be lower, digestion efficiencies do not match those obtained in other digester systems. Figure 25 presents a diagram of a typical covered lagoon.

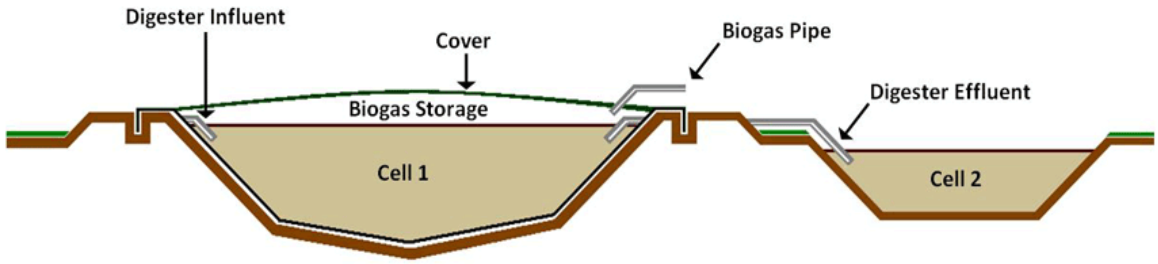

Figure 25. Diagram of a Covered Lagoon

Covered lagoon systems have been used quite extensively in hundreds of wastewater treatment facilities for cassava starch manufacturing in India.

Figure 26. Covered Lagoon

Source: USDA, 2012

Up-Flow Anaerobic Sludge Blanket (UASB)/Induced Blanket Reactor (IBR)

UASB/IBR (shown in Figure 27) is vertical cylindrical tank where the influent is added continuously from the bottom of the reactor and flows upward. The reactor contains a suspended sludge blanket comprised of microbial granules (1–3 mm in diameter). Microbial granules are small collections of microorganisms that are responsible for the biochemical reactions of the AD process (organic degradation and biogas production) and, due to their weight, cannot be washed out of the system with the upflow of the effluent (SSWM, 2018). Produced biogas rises to the top of the cylinder with the clarified effluent, and influent flow keeps the bacteria suspended in the reactor.

These systems are best suited for consistent, homogenous waste streams and are relatively simple to design and build. The challenging part of the system may be developing the granulated sludge. Chemicals known as flocculants need to be added to the system to help the formation of the granules, and the sludge blanket takes months to reach its processing capacity before the system can start operation.

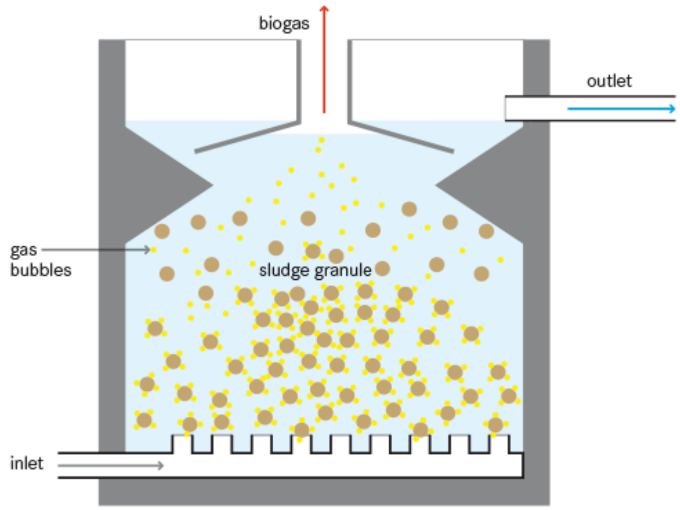

Figure 27. Diagram of a UASB Reactor

Source: SSWM, 2018

These systems are considered more advanced technology and require constant availability of water and electricity. UASB is a well-established process for centralized wastewater treatment plants and industrial wastewater treatment, and it has also been used to process water from brewery, distillery, food processing, and pulp and paper waste. The total solid content of the feedstock can be up to 12 percent. UASB systems allow for codigestion if all the feedstocks meet the criteria to be processed in this kind of system. UASBs are commonly used in India for lean feedstocks with low energy density or low volatile solids (VS)/chemical oxygen demand (COD)/biochemical oxygen demand (BOD). These include distillery effluents, starch industry wastes, sewage, paper mill effluents, slaughterhouse wastewater, and dairy industry wastewater.

Fixed Film/Attached Media Digester/Anaerobic Filters

Fixed film/attached media/anaerobic filters are vertical cylindrical tanks made of concrete or steel with an impermeable flexible cover on the top for the collection of biogas. In these reactors, microorganisms that facilitate the feedstock biodegradation and biogas generation are attached as a film to a medium, typically ceramics or plastics. The inflow of feedstock may be at either the top or bottom of the reactor in a downflow or upflow configuration, respectively. As the feedstock flows through the digester, it is processed by the microorganisms on the film. These systems are best suited for a very low total solid content in the feedstock (1 to 5 percent) and therefore have the greatest application in processing wastewaters, and are extensively used in India. Figure 28 shows an upflow configuration with solids being separated and the manure liquid fed into the digester.

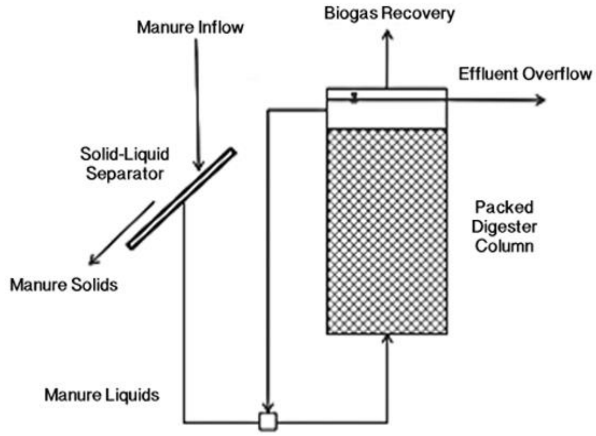

Figure 28. Example Fixed Film Digester

Source: eXtension Foundation, 2019

Plug Flow Digester

Plug flow digesters are constructed with concrete or steel, are typically long and narrow, with an impermeable gas-collecting cover. Contents move through the digester as new material is added. Modified plug-flow systems use shafts for mixing the substrate in the direction perpendicular to the direction of flow and moving the material through the reactor. These systems can handle manure with animal bedding, food waste, and yard waste. When processing food waste and yard waste, they need to be preprocessed to homogenize the material. Figure 29 presents a diagram of a typical plug flow digester.

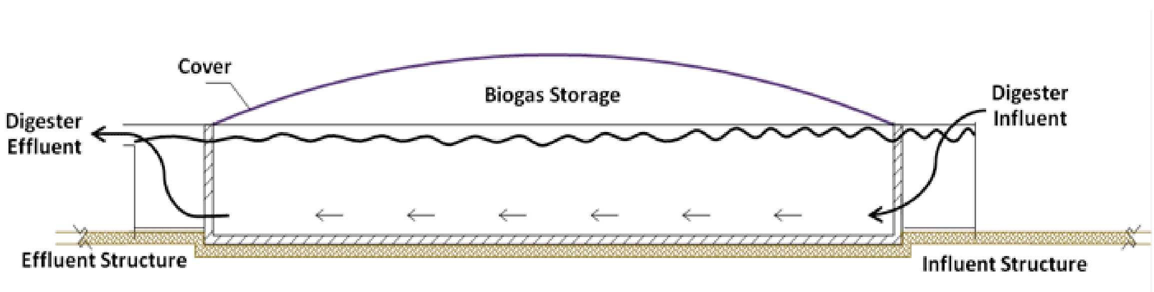

Figure 29. Diagram of a Plug Flow Digester

These systems are considered simple and robust to a certain extent, as the reactors can tolerate contamination and no significant preprocessing of the material is required. These systems have no limitations with reference to optimal climate conditions, have a retention time of more than 15 days, and the material processed can have a solids content of up to 40 percent.

"Garage"-Style Dry AD Systems

"Garage"-style dry AD systems (shown in Figure 30 and Figure 31) are simple by design and very robust. These systems are long tunnels with perforated floors, and flexible impermeable covers for gas collection. Material is processed in batches; once the system is filled, the doors are closed and the material is left in the reactor for an average of 21 days. This system can process material with a solid content in excess of 50 percent without additional moisture needed.

Dry AD systems of this kind gained popularity in Europe when the disposal of non-processed organics was banned. These reactors are very flexible regarding the level of contamination in the feedstock, allowing for digestion of organic waste from MSW, including mixed food and green waste.

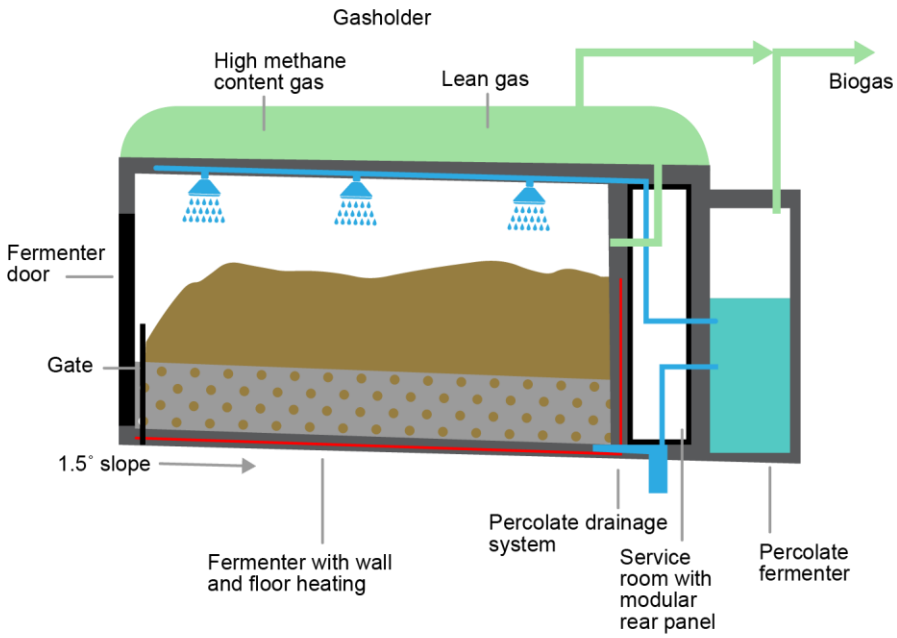

Figure 30. Diagram of a Dry AD System

Figure 31. Dry AD System

These systems typically include an above-ground digester where the feedstock is added, airtight doors, and an underground percolator chamber. Leachate produced during decomposition of the material in the digester is collected in the percolator chamber and spayed over the material in the main digester. These systems produce biogas from the material in the main reactor and the leachate in the percolator chamber. Recirculation of the leachate allows for these systems to run as thermophilic systems, which increases the biogas production and the rate of degradation. While the capital and operating costs of these digesters are expected to be lower, these types of systems are also generally associated with lower digestion efficiencies.

A large-scale (4 MW) facility using this technology is currently processing segregated municipal solid waste in Solapur, Maharashtra. This is the only pilot facility of this type in India and is yet to be replicated.

Anaerobic Sequencing Batch Reactors (ASBRs)

ASBRs are typically cylindrical, made of concrete, above-ground, with an impermeable roof below which gas is collected. They are used to process wastewater or treat dilute wastes (e.g., manure handled as a slurry). Feedstock is added and removed from the reactor in batches.

These reactors include four processing phases in sequence as follows:

1. Filling phase,
2. Reaction phase
3. Settling phase
4. Decanting phase.

These reactors can process material with 2.5 to 8 percent solids in a relatively short retention time (up to 5 days). ASBR systems work in all climates and are suitable for codigestion of different organic feedstocks. These digesters are not typically used in India due to higher costs and lower efficiencies.

4.3 References

American Biogas Council. 2018. Biogas Projects. Available: *https://americanbiogascouncil.org/resources/biogas-projects/*.

European Biogas Association. 2017. EBA Statistical Report 2017. European Biogas Association. Available: *http://european-biogas.eu/2017/12/14/eba-statistical-report-2017-published-soon/*. Accessed 5/29/2019.

eXtension Foundation. 2019. Farm Energy. Types of Anaerobic Digesters. Available: *https://farm-energy.extension.org/types-of-anaerobic-digesters/*. Accessed 5/29/2019.

IRENA. 2017. Biogas for Domestic Cooking: Technology Brief. International Renewable Energy Agency, Abu Dhabi Brief, International Renewable Energy Agency, Abu Dhabi.

Singh, S.K. 2014. Waste and By-Product Utilization. Lesson 6. Biogas. Available: *http://ecoursesonline.iasri.res.in/mod/page/view.php?id=1430*. Accessed 5/29/2019.

SSWM. 2018. Upflow Anaerobic Sludge Blanker Reactor (UASB). Sustainable Sanitation and Water Management. Available: https://www.sswm.info/water-nutrient-cycle/wastewater-treatment/hardwares/semi-centralised-wastewater-treatments/upflow-anaerobic-sludge-blanket-reactor-%28uasb%29. Accessed 5/29/2019.