https://cejsr.academicjournal.io

Method on Anaerobic Biogas Generation from Cow Dung and Water Hyacinth with Reference to Quality of Gas and it's Effect on Public Surroundings

Nitin Gupta
Assistant Professor, Dept. of Chemistry, Government College, Kota, Rajasthan, India

S. M. Nafees, Seema Agarwal
Associate Professor, Dept. Of Chemistry, Government College, Kota, Rajasthan, India

ABSTRACT

Under the right conditions, liquid manure will break down into biogas and a low-odor effluent. Biogas can be burned to produce heat, electricity, or both the anaerobically-digested manure, can be stored and applied to fields with significantly less odor than stored, untreated liquid manure. Anaerobic digestion does not reduce the volume or nutrient value of manure. If dilution water is added to the system, the volume of material to handle is increased.The following test can help you determine if anaerobic digestion is a viable option for your farm. If most of the following statements describe your farm, anaerobic digestion may be compatible with your operation.Manure is currently handled as a liquid. Very little bedding or frozen manure is handled and the manure in the handling system is free from high levels of copper sulfate and antibiotics.Odor control is a major concern.There is space on the farm to expand the manure handling system with the possibility for gravity flow from a barn to an anaerobic digester or from a digester to a manure storage.Someone on the farm has the interest, time, and technical skills to learn about the anaerobic digestion process, make repairs, and perform general maintenance on equipment.Resources are available to finance an anaerobic digestion system.Adhering to recommended safety practices is standard procedure on the farm.

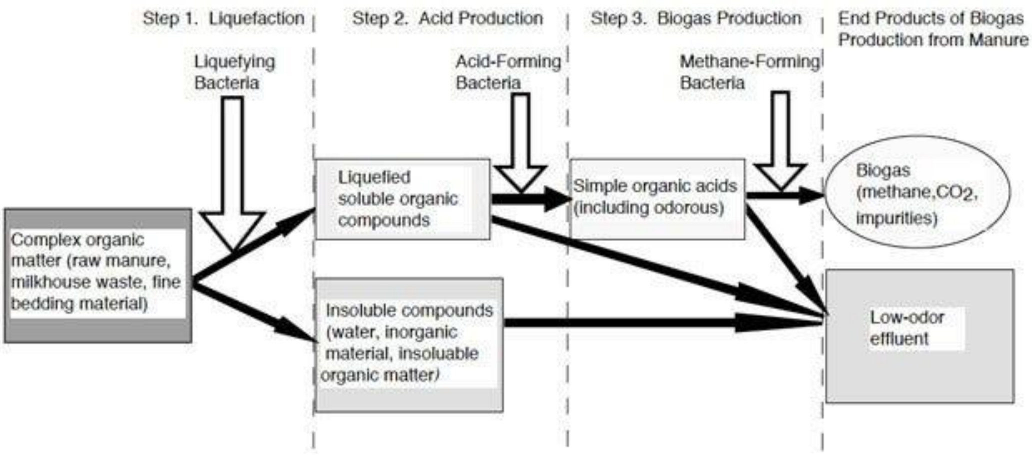
KEYWORDS: *anaerobic, biogas, generation, cow dung, water hyacinth, quality, public surroundings.*

Introduction

Anaerobic digestion, or the decomposition of organic matter by bacteria in the absence of oxygen, occurs naturally in liquid manure systems. The lack of oxygen and abundance of organic matter in liquid manure provide the proper conditions for anaerobic bacteria to survive. Unfortunately, uncontrolled anaerobic decomposition can cause the foul odors sometimes associated with liquid manure storage and spreading. However, controlled anaerobic decomposition not only[1,2] can reduce the odors in liquid manure systems, but also can turn odorous compounds and organic matter into energy. The effluent remaining after controlled anaerobic decomposition, equal in volume to the influent material, is liquefied, low in odor, and rich in nutrients. This digested material is biologically stable and will resist further breakdown and odor production when stored under normal conditions.[3,4]

Anaerobic bacteria transform manure and other organic material into biogas and a liquefied effluent during the three stages of biogas production (Figure 1).

https://cejsr.academicjournal.io



In the liquefaction stage, liquefying bacteria convert insoluble, fibrous materials such as carbohydrates, fats and proteins into soluble substances. However, some fibrous material cannot be liquefied and can accumulate in the digester or can pass through the digester intact. Water and other inorganic material also can accumulate in the digester or pass through the digester unchanged. Undigested materials make up the low-odor, liquefied effluent. Most of the liquified, soluble compounds are converted to biogas by the acid- and methane-forming bacteria during steps 2 and 3 of biogas production. In the second stage of anaerobic digestion, acid-forming bacteria convert the soluble organic matter into volatile acids--the organic acids that can cause odor production from stored liquid manure. Finally, methane- forming bacteria convert those volatile acids into biogas--a gas composed of about 60 percent methane, 40 percent carbon dioxide, and trace amounts of water vapor,[5,6] hydrogen sulfide, and ammonia. Not all volatile acids and soluble organic compounds are converted to biogas; some become part of the effluent. Methane-forming bacteria are more sensitive to their environment than acid-forming bacteria. Acid-forming bacteria can survive under a wide range of conditions while methane-forming bacteria are more demanding (Figure 2). Under the conditions typical of liquid manure storages, more acid-forming bacteria can survive than methane-forming bacteria. Therefore, acids are formed and are not converted to biogas. This excess of volatile acids can result in a putrid odor. In a controlled, optimum environment, methane-forming bacteria survive and convert most of the odor-producing volatile acids into biogas.[7,8] Conditions that encourage activity of both acid- and methane-forming bacteria include:

- An oxygen-free environment
- A relatively constant temperature of about 95 ℉
- A pH between 6.6 and 7.6
- A consistent supply of organic matter to "feed" upon
- For consistent operation of an anaerobic digester, the manure that "feeds" the bacteria should be:
- A flow able liquid, about 12 percent solids or less (for pump or flow requirements)
- Not frozen
- Free from excess amounts of medication, feed additives, or chemical washes
- Supplied fresh to the digester at least twice a day
- A uniform slurry of manure that does not separate easily,[9,10] such as:
- Dairy manure from scrape systems which can include small amounts of fine, organic bedding such as sawdust, waste feed, milking center waste or dilution water

- Swine manure from pull-plug or scrape systems
- Poultry manure, diluted to about 10 percent solids with the grit settled out[11,12]

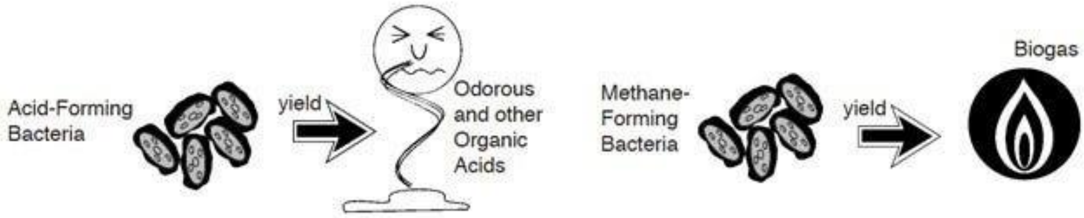


Figure 2. Conditions for survival of acid- and methane- forming bacteria.

Acid-forming bacteria can survive

- with temperature fluctuations
- in a wide range of pH conditions
- with or without oxygen
- on a broad range of organic compounds as a food source[13]

Methane-forming bacteria can survive only

- if temperature is held relatively constant
- in a narrow band of pH conditions
- without oxygen
- on simple organic acids as a food source

Anaerobic digestion is simply a continuation of the animal's digestive system--a process to turn manure into energy and effluent, just like an animal turns feed into energy and manure.[14,15]

Anaerobic Digestion System

An anaerobic digestion system (Figure 3) can provide an optimal environment for controlled anaerobic digestion. A typical system consists of liquid manure handling equipment, a heated anaerobic digester, gas utilization equipment, safety equipment, and effluent storage and handling systems. The anaerobic digestion system is an addition to the manure handling scheme--a step for manure processing between the barn and the storage facility. It does not replace any part of a typical manure handling system. [15, 16]

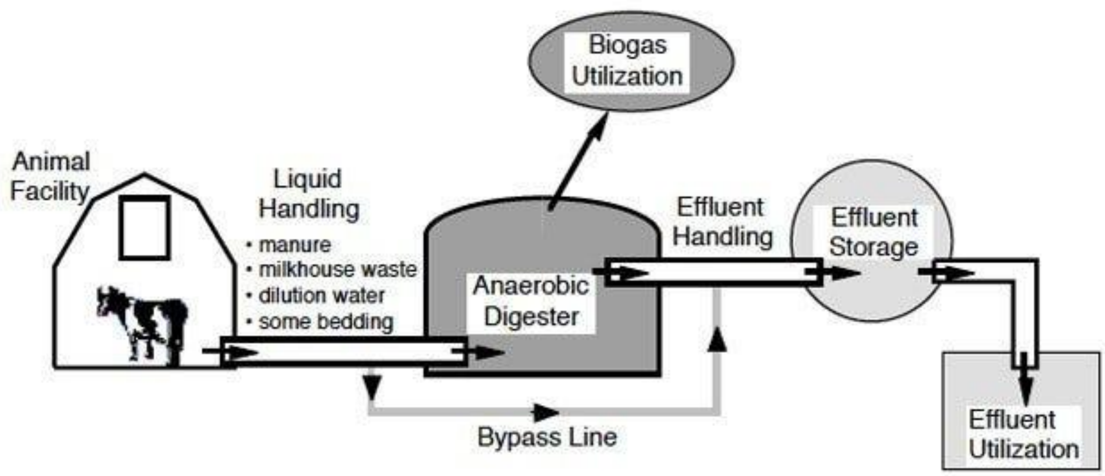


Figure 3. Schematic diagram of a typical anaerobic digestion system. (Adapted with permission from Anaerobic Digesters for Dairy Farms published by Cornell Cooperative Extension.

https://cejsr.academicjournal.io

Liquid manure handling system.

A liquid manure handling system (such as the system used to transport liquid manure from a barn to a storage facility) transports manure from the animal housing facility to the anaerobic digester, and from the digester to the storage facility or spreader. When possible, the use of gravity flow is encouraged to reduce the energy consumption and complexity of the handling system. A bypass line routes manure around the digester when the manure is unsuitable for digestion or the digester is not operating.[17,18]

Anaerobic digester.

An anaerobic digester is a sealed, heated tank which provides a suitable environment for naturally-occurring anaerobic bacteria to grow, multiply, and convert manure to biogas and a low-odor effluent. Typical digesters have been insulated, squat, silo-like structures or in-ground rectangular or round concrete tanks. Rigid or flexible covers have been used. They are designed to hold about 20 days of manure and a small supply of biogas. Manure, added daily to the digester, remains inside for about 20 days, the retention time, before flowing to the storage facility or spreader. Because there is no volume reduction with anaerobic digestion, the same amount of material added daily to the digester is also removed daily. While manure is flowing through the digester, the bacteria convert organic matter to biogas and effluent.[19]

During the retention time, lightweight material such as bedding or animal hair can float to the top of the digester, forming a crusty scum and heavy or insoluble material such as dirt can settle to the bottom. Settling reduces the effective volume of the digester and can cause incomplete digestion and odor problems, while crusting can keep gas from escaping the surface of the digesting manure. To control settling and scum formations, material in the digester can be agitated by a slurry pump, a mechanical stirrer, or strategic placement of the heating pipes. Slurry pumps are an effective way to keep material in the digester well-mixed. Mechanical mixing adds complexity to the system, but can aid thermal uniformity, reduce settling, and break up crust formation. Mechanical mixing may be necessary for certain manure handling systems such as flush systems where solid and liquid portions may separate easily into distinct layers within the digester. Strategic placement of the heating pipes will encourage thermal circulation and reduce settling problems.[20]

The heating system is a critical part of the anaerobic digester. Heating pipes in which hot water circulates must be able to heat all material entering the digester to 95℉ and to resist corrosion from manure. Adding manure to the digester as soon as possible after it is excreted from the animal will help minimize heating requirements.

Digester size

To get an idea of the size of an anaerobic digester, consider one designed for 200 milking cows with a 20 day retention time:

Assuming each high-producing milking cow produces 2.2 ft^3 manure per day, the daily volume of manure from these milking cows would be:

200 cows x 2.2 ft^3 manure/day/cow = 440 ft^3 manure/day

If dilution water is needed for manure flowability or added from the milking center at a rate of 3 gallons per cow per day, the additional volume added daily would be:

200 cows x 3 gallons water/cow/day ÷ 7.5 gallons water/ft^3 water = 80 ft^3 water/day

The total material added daily to the digester, therefore, would equal:

440 ft^3 manure/day + 80 ft^3 water/day = 520 ft^3 material/day[21,22]

To hold 20 days' worth of manure and water, the digester volume would need to be:

520 ft^3/day x 20 days = 10, 400 ft^3

A digester with a rigid cover, a 3 ft head space for gas collection, and a material volume (no bedding included) of 10,400 ft^3, would be approximately 15 ft deep and 33 ft in diameter.

Gas utilization equipment.

Biogas is collected in the head space of the anaerobic digester (or under the flexible cover) and has about 60 percent of the energy density of natural gas (methane)--about 600 BTU/ft^3. With minor equipment modifications, biogas can be used in the same applications as LP gas, propane, or natural gas.

Biogas is best suited for stationary continuous operation because of its low energy density, the corrosive nature of some of the impurities and the constant production rate. Biogas utilization equipment typically consists of either an engine-generator set with electric utility hook-up, an engine operating hydraulic or air pumps, or a gas boiler. Utilization equipment should be housed in a separate equipment shed apart from the digester to prevent corrosion.[23,24]

Operating biogas-powered equipment continuously keeps the equipment temperature high enough to prevent condensation and sulfuric acid formation. Sulfuric acid is highly corrosive and can ruin expensive engines or boilers. Because biogas is a gas and not a liquid fuel, it is not practical for fueling vehicles. It would take 240 ft^3 of biogas to produce the same energy as one gallon of fuel oil. Biogas cannot feasibly be compressed to a liquid fuel due to its low energy density.

For electricity production, biogas is piped to an internal combustion engine. The engine drives a generator to produce electricity that can be used on the farm or sold. To maintain continuous operation, the engine throttle is adjusted to balance biogas use with production. Waste heat from the engine is used to heat the digester and for other farm heating needs. Most systems produce about 2 kilowatt-hours per day per 1,400 pound cow. Many utility companies in Pennsylvania pay only about 2¢ per kilowatt-hour for farm-produced electricity, much less than the consumer price for a kilowatt-hour. Therefore, maximizing the replacement of purchased energy with farm-produced energy will improve the economics of on- farm electricity generation.[25,26]

Safety equipment.

Because biogas is a potentially dangerous gas, safety devices such as gas detectors, flame traps, physical barriers, and warning signs (Figure 4) control and minimize the hazards of biogas and manure storage. See the next section and other resources for more detailed information about required safety devices.

Figure 4. Example of a warning sign placed outside an anaerobic digester.

Safety Hazards

Anaerobic digesters are confined spaces which pose a potential immediate threat to human life. They are designed to seal out oxygen, making death by asphyxiation possible within seconds of entry.

Toxic gases such as hydrogen sulfide and ammonia accumulate inside a digester. Never enter an empty digester without extensive venting with mechanical fans, checking for toxic gases with gas detection equipment, and following safe entry procedures. Natural ventilation is not enough to remove toxic gases from the digester or to provide sufficient breathable air. Dense hydrogen sulfide gas will sink to the bottom of the tank, lighter ammonia will linger in the top of the tank, and neither gas will escape without mechanical ventilation. Moreover, methane is explosive when mixed with air in concentrations of 5 to 15 percent. A leak in a gas line will create a fire hazard.[27,28]

Anaerobic digesters are at least as dangerous, if not more so, than manure pits. For more information about safety concerns associated with anaerobic digesters, call the National Institute for Occupational Safety and Health at 1-800-35-NIOSH. See Penn State Extension Fact Sheet, Manure Storage Hazards, for an outline of safety procedures for entering manure pits.

Potential Advantages of Controlled Anaerobic Digestion

- There is substantially less odor with digested manure than there is with stored liquid manure.
- Energy produced from biogas offsets the cost of the investment.
- The nutrient content of digested manure is equal to that of raw manure.
- Digested manure is more liquefied than raw manure, making it easier to pump long distances.
- Digested manure is biologically stabilized, making it easier to store for long periods without odor problems.
- Homogenous digested manure performs well in liquid application systems.
- Rodents and flies are less likely to be attracted to digested manure.
- Emissions of methane from liquid manure storage areas are reduced.[29]

Potential Disadvantages of Anaerobic Digestion

- Initial investment may be costly for a digestion system. Bankers and lenders may be wary of lending money for these systems.
- The digester requires proper care and feeding, just like an animal. Technical knowledge of the digestion process and good management are required.
- Labor is required for preventive and unscheduled maintenance. Ideally, one person will be in charge of the digester, and the digester takes precedence over that person's other farm duties.
- Daily maintenance tasks are minimal, but weekly oil changes, regular engine overhauls, and periodic digester clean-out are required.
- There is no reduction in the amount of manure to be handled. If water is added to the system, the volume is increased.
- Nutrient conservation may be undesirable on a farm with excess nutrients to manage.
- Much of the nitrogen in raw manure is converted from its organic form to ammonium. Ammonium can be transformed to either ammonia or nitrate. Ammonia can be lost from unincorporated, field-applied manure. Nitrate can be leached through the soil and may eventually reach groundwater.
- Field application and management to reduce nitrogen losses may be more demanding for digester effluent than for untreated liquid manure.
- Anaerobic digesters can be a farm safety hazard.[30]

Alternatives to Electric Generation from Anaerobic Digesters

With minor equipment modifications, biogas can be used as a substitute for natural gas. Running a gas-fired boiler is an inexpensive and efficient method to use biogas. The obstacle will be finding uses for the heat, especially in the summer. Absorption (heat-activated) cooling systems are a promising technology for using excess heat, but currently have a high initial cost.

Another option is to remove carbon dioxide and hydrogen sulfide from the biogas and sell it as natural gas. Scrubbing the gas, finding a market, providing the buyer with a dependable supply of gas, and maintaining the distribution equipment require money, time, maintenance, and management. Additionally, natural gas will sell for a much lower price than electricity. Although other options are available for biogas utilization, electricity is the most versatile and valuable energy product from biogas.

Planning for Future Changes

If expansion of an animal production operation or a new facility is planned but an anaerobic digestion system is not included in the layout, leaving adequate space and installing a compatible manure handling system could add to the flexibility for the future. There may be a time when investing in a digester is just the right step for a farm.

Separating solids prior to anaerobic digestion and digesting only the organic matter in the liquid portion of the manure may produce a higher quality biogas (70 percent methane has been observed) and typically will reduce crusting and settling problems. The solids can be field-applied, sold, or composted and used for animal bedding. Separation and marketing of solids can generate farm income. Replacing bedding with composted solids could be a money-saver if a substantial amount of bedding currently is purchased and a solids separator is owned. However, if a solids separator needs to be purchased, the savings in bedding costs may not cover the cost of solids separation.[31,32]

Future Technology

In the future, a "fixed film" digester may be available. In this type of system, a digester is filled with a medium such as rocks or plastic mesh. The medium acts as a resting and growing place for the bacteria. Many bacteria, instead of being flushed out with the effluent, remain attached to the medium inside the digester. By retaining the bacteria within the fixed film digester, bacteria can consume more organic matter than in standard digesters. Therefore, in a short period, a smaller, fixed film digester can treat the same amount of organic matter and produce the same quantity of biogas as a larger, standard, digester. The retention time in a fixed film digester potentially can be reduced from twenty to between one and three days, significantly reducing digester volume and cost. In a fixed film digester, solids need to be separated and removed from the loading slurry prior to digestion. Fixed film digesters are only in the research phase, however, and a full-scale farm digester has yet to be tested.

Discussion

Water hyacinth can be used in biogas production because it has high hemicellulose content compare with other single organic components. Hemicellulose is complex polysaccarides which is polymer composite which if it hydrolized produce derivative mixture product that can be treated with anaerobic digestion methode to produce two simple mixture compounds which are methane and carbon dioxide that commonly called biogas . Anaerobic digestion (AD) has been extensively used to convert organic waste streams from various sources, such as agricultural, industrial, and municipal solid waste, to biogas. The AD process can operate in both liquid and solid states in terms of total solid (TS) content. In general, the TS content of liquid AD (L-AD) systems ranges from 0.5 to 15%, while solid-state AD (SS-AD) systems usually operate at TS contents of higher than 15% .[30]

Several studies of biogas production from lignocellulose biomass using water hyacinth and L-AD methods had been conducted. A research on biogas using waste of fisheries in the form of offal, filth, and gills as the main substrate had been done. Biogas production that has been resulted on F/M ratio 0.2 with total maximum methane 164.7 l / kg CODMn. Besides that, F/M ratio gave a significant effect to the retention time (HRT). Time retention that obtained from F/M ratio 0.2, 0.4, and 0.6 each were 36, 13, and 19 days . Research also did on hydrogen production and methane from banana peel. The result was, the best perform from one fermentation phase was observed on F/M from 5.0. On this condition, methane yield, production level, and potential were 251.3 mL g-1 VS, 2.05 mL h-1, and 352.9 mL. The result of hydrogen and methane from 209.9 and 284.1 mL g-1 VS mL g-1 VS accomplished on F/M from 5.0 in the second step process .

Water Hyacinth is one of the alternative from agricultural waste that can be used for biogas because a high hemicellulose content F/M ratio can take effect to biogas production. The smaller F/M ratio, the amount of biogas production will be higher. The highest biogas production was on F/M ratio 10.01 (content of 50% rumen). On this research, from the four F/M ratios that have been researched, the most optimum F/M ratio was on 10.01 with optimum total solid 6.76%. The biggest biogas yield was on F/M ratio 10.01 in amount of 127.071 ml/ gr TS started on the fourth day. The daily biogas production (A) and production rate constants (U) respectively 151.910 ml/ gr TS and 2.624 ml/ gr TS.

Results

Resultantly, digesters of cow dung manure produced better results for biogas production. This could be because of cow dung has high nitrogen concentration and favourable pH of 7.01 as compared to fermentation of other series digesters. It also contains adequate amount of carbon, oxygen, hydrogen, sulphur, phosphorous, potassium, calcium, magnesium and a number of trace elements helpful for bio-digestion. The results also show that digesters with dried water hyacinth (DWH) produced slightly less biogas in comparison to digesters with cow manure (CM). This indicated the fact that substrates for methanogenic bacteria were readily available in the media. However, the time period for attaining the maximum production rate was longer (about 27 - 48 days) in comparison to cow manure (21 - 42 days). It can be explained as in case of water hyacinth bacteria needed a longer time period to grow for biogas production whereas in case of ruminants waste such as cow manure pathogens were already present and bacterial growth takes comparatively in lesser time for biogas production.[31]

Conclusions

Biogas production from water hyacinth can effectively manage the aquatic weed as well as mitigate environmental pollution which is caused by burning of fossil fuel. But the presence of lignin in water hyacinth makes hydrolysis the bottleneck of anaerobic digestion thereby delaying the hydrolysis phase and producing decreased amount of biogas. Therefore pretreatment of water hyacinth is essential for accelerated hydrolysis period and enhanced biogas production. In this study, thermal, electro hydrolysis and biological (microbial) pretreatment were investigated to enhance solubilisation of water hyacinth. Hot air oven pretreatment of water hyacinth at 90ºC for 1h demonstrated the highest solubilisation and biogas production when compared to the other pretreatment techniques. The pressed cane stalk is a potential source of raw material for biogas production, and that it can be mixed with cattle slurry up to the level of 56.7% on a dry matter basis without seriously reducing total gas production. However the fibrous PCS degrades slowly and a longer retention time would be needed to extract the same volume of gas as for pure slurry. The addition of PCS depresses the pH of the mixture and this leads to a lag phase whose length is related to the pH. The lag phase can be reduced by the addition of urea. [32]

References

1. "Anaerobic Digestion". NNFCC Renewable Fuels and Energy Factsheet. National Non-Food Crops Centre. Retrieved 22 November 2011.
2. Koyama, Tadashiro (1963). "Gaseous metabolism in lake sediments and paddy soils and the production of atmospheric methane and hydrogen". Journal of Geophysical Research. 68 (13): 3971–3973. Bibcode:1963JGR....68.3971K. doi:10.1029/JZ068i013p03971.
3. Pamatmat, Mario Macalalag; Bhagwat, Ashok M. (1973). "Anaerobic metabolism in Lake Washington sediments" (PDF). Limnology and Oceanography. 18 (4): 611–627. Bibcode:1973LimOc..18...611P. Doi:10.4319/lo.1973.18.4.0611. Archived from the original (PDF) on 16 December 2013.
4. Zehnder, Alexander J. B. (1978). "Ecology of methane formation". In Mitchell, Ralph (ed.). Water Pollution Microbiology. Vol. 2. New York: Wiley. pp. 349–376. ISBN 978-0-471-01902-2.
5. MacGregor, A. N.; Keeney, D.R. (1973). "Methane formation by lake sediments during in vitro incubations". Journal of the American Water Resources Association. 9 (6): 1153–1158. Bibcode:1973JAWRA...9.1153M. Doi:10.1111/j.1752-1688.1973.tb05854.x.
6. "Anaerobic digestion reference sheet" (PDF). Waste.nl. Archived from the original (PDF) on 5 October 2011. Retrieved 25 October 2007.
7. Tabatabaei, Meisam (2010). "Importance of the methanogenic archaea populations in anaerobic wastewater treatments" (PDF). Process Biochemistry. 45 (8): 1214–1225. doi:10.1016/j.procbio.2010.05.017.
8. "Agricultural Biogas". Clarke-energy.com. Retrieved 8 November 2011.
9. "Jenbacher Gas Engines". Clarke-energy.com.
10. ^ "Anaerobic Digestion Strategy and Action Plan" (PDF). defra.gov.uk. Retrieved 19 January 2012.
11. "Jyllands-Posten". 29 December 2011. Retrieved 19 January 2012 – via Google Translate.
12. "AgSTAR Data and Trends". United States Environmental Protection Agency. 3 July 2019. Retrieved 18 October 2019.
13. "Evaluation of Opportunities for Converting Indigenous UK Wastes to Fuels and Energy" (Report). National Non-Food Crops Centre. NNFCC 09-012. Archived from the original on 20 July 2011.
14. Adapted from Beychok, M. (1967). Aqueous Wastes from Petroleum and Petrochemical Plants (First Ed.). John Wiley & Sons. LCCN 67019834.
15. Fergusen, T. & Mah, R. (2006) Methanogenic bacteria in Anaerobic digestion of biomass, p49
16. "The biogas plant". Unu.edu. Retrieved 5 November 2007.
17. Anaerobic digestion Archived 5 October 2011 at the Wayback Machine, waste.nl. Retrieved 19.08.07.
18. Sleat, R.; Mah, R. (2006). "Hydrolytic Bacteria". Anaerobic digestion of biomass. p. 15.
19. Boone, D.; Mah, R. (2006). Transitional bacteria in anaerobic digestion of biomass. p. 35.
20. "What is anaerobic digestion?" (PDF). Sop.inria.fr. Retrieved 24 October 2007.

https://cejsr.academicjournal.io

21. "Anaerobic digestion". Biotank.co.uk. Archived from the original on 12 October 2007. Retrieved 24 October 2007.
22. "How It Works". Greenthefuture.com. Anaerobic Digester. Archived from the original on 11 October 2016. Retrieved 23 February 2016.
23. "Landfill Gas & Biogas Analyzers | Nova Gas". Nova Gas. Retrieved 23 February 2016.
24. A, Igoni Hilkia; Abowei, M. F. N.; Ayotamuno, M. J.; Eze, C. L. (16 January 2009). "Comparative Evaluation of Batch and Continuous Anaerobic Digesters in Biogas Production from Municipal Solid Waste using Mathematical Models". Agricultural Engineering International: CIGR Journal. ISSN 1682-1130.
25. "COMPARING OF MESOPHILIC AND THERMOPHILIC ANAEROBIC FERMENTED SEWAGE SLUDGE BASED ON CHEMICAL AND BIOCHEMICAL TESTS" (PDF). aloki.hu. Retrieved 23 February 2016.
26. "Low and High Solid Anaerobic Digestion Technology". www.theecoambassador.com. Retrieved 23 February 2016.
27. "Anaerobic Digestion Systems". www.wtert.eu. 2008. Retrieved 2 February 2016.
28. Aikantechnology.com Archived 6 February 2012 at the Wayback Machine Retrieved 10. Feb. 2012.
29. Anaerobic digestion Archived 13 June 2009 at the Wayback Machine, energy.ca.gov. Retrieved 18.06.09.
30. BIOPAQ IC, paques.nl. Retrieved 19.08.07.
31. Biological processes with Biomar technology Archived 27 February 2014 at the Wayback Machine envirochemie.com. Retrieved 24.10.2012.
32. Song, Y.C.; Kwon, S.J.; Woo, J.H. (April 2004). "Mesophilic and thermophilic temperature co-phase anaerobic digestion compared with single-stage mesophilic- and thermophilic digestion of sewage sludge". Water Res. 38 (7): 1653–62.