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Review Paper

Operating Procedures for Efficient Anaerobic Digester Operation

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Abstract

Ignorance or unknown fear of handling anaerobic digester should be removed first for its successful operation. While the biochemical reactions inside the digester are complex, concurrent and if not regulated, they become counterproductive resulting into souring or shut down of the digester. For this purpose, detailed procedure is given by focusing underlying principals which regulate biogas output. Finally, factors affecting digester performance are summarize so that maximum output of biogas could be generated, leaving little BOD/COD in the effluent to be used as organic manure without defying the norms set by State Pollution Control Board. For the sake of completeness, method of ORP estimation is given, since its narrow and critical range determines success or failure of anaerobic digestion.

Keywords: Biogas, methane, anaerobic digestion, solid waste, organic loading rate,

Introduction

Installation and operating the biogas plants is not new to India. In fact, *Khadi* and Village Industries Commission (KVIC), amongst its various mandates, were assigned a program for recycling rural agri-waste for the production of biogas, commonly known as *gobar gas*. Accordingly, *gobar gas* plants were installed in millions to generate *gobar gas* for meeting energy needs of rural population. However, it is on record that hardly 0.35 million plants are operational, while the rest have become defunct. Its critical analysis has revealed that either right operating procedure was not in place or personnel manning these plants were not sufficiently trained to operate them efficiently. The theme of this article precisely focuses on this aspect.

Starting up the digester

Substrate: The choice of a substrate depends on availability, its cost, ease of handling, safety for operators, storage and requirements for feeding. It induces hydrolysis of particulate matter initially to organic acids and finally to volatile fatty acids (VFAs).

Inoculum: Seeding of the digester warmed up to 35°C with fresh cattle dung/manure may be useful as it contains a consortium of microbes to undertake activities from hydrolysis, acidogenesis and acetogenesis to methanogenesis. Alternatively, an inoculum comprising of secondary sludge: primary sludge (1:10) may be used.

While, secondary sludge is highly concentrated with facultative anaerobes, primary sludge contains facultative anaerobes and methane-forming anaerobes. Therefore, it is obvious that anaerobic digester cannot be successfully seeded with secondary sludge alone. Once an anaerobic digester has started operating efficiently, it can be fed with secondary sludge alone. During start-up or when the efficiency of the digester deteriorates, requisite amount of fresh cattle manure is added daily, until successful start-up and improved efficiency is obtained.

Loading: During start-up, loading to the digester should proceed slowly. While doing so careful monitoring and control of pH as well as alkalinity are essential until the digester attains pH in 6.8-7.2 range. For this purpose, different alkalis could be added to maintain desired pH, alkalinity and buffering capacity to neutralize acids within the digester.

Tips for pH and alkalinity maintenance: When the digester pH is 7.2 or lower, NH_4^+ is favored. When the digester pH is greater than 7.2, NH_3 is favored. Ammonia-nitrogen concentration beyond 1500-3000 mg/liter is not only inhibitory; it creates an additional problem of foam and scum generation.

Digester stability: Approximately one month is required to achieve a steady-state digester. Once the digester is stabilized, monitor VFAs: alkalinity ratio.

Sludge feeding: Sludge feeding or organic loading rate (OLR) is expressed in terms of volatile solids (VS). Typically, it is 0.5–0.6 kg VS/m^3/day and recommended loading is 3.2–7.2 kg VS/m^3/day.

Thickening of sludge is an important operational factor affecting the digester performance. Raw sludge or feed sludge, which has 3–6 % solids, reduces destruction of volatile solids as well as methane production. Digested sludge and supernatant are withdrawn from the digester on a routine basis to be used as liquid organic manure.

Common operational problems: Associated with anaerobic digesters, these are over-pumping of raw sludge and excessive withdrawal of the digested sludge. To avoid/minimize these problems, two significant retention times: (i) solid retention time (SRT) and (ii) hydraulic retention time (HRT) need to be considered.

SRT is usually greater than 12 weeks. High SRT values are advantageous as they maximize sludge removal capacity, reduce requisite digester volume and provide buffering capacity for shock loadings and toxic compounds in wastewaters and sludges. Biological acclimation to toxic compounds permits significant reduction of BOD/COD minimizes fluctuations in response to toxicants and maximizes biogas production. These activities are catalyzed by the following categories of bacteria summarized in table-1.

Table-1
Approximate generation time of important groups of wastewater bacteria

Bacterial group	Function	Generation time
Aerobic organotrophs	Floc formation and degradation of soluble organics in the activated sludge and trickling filter processes	15–30 min
Facultative and anaerobic organotrophs	Hydrolysis and degradation of organics in the anaerobic digester, besides floc formation and degradation of soluble organics in the activated sludge and trickling filter processes,	15–30 min
Nitrifying bacteria	Oxidation of NH_4^+ and NO_2^- in the activated sludge and trickling filter processes	2–3 days
Sulfate reducing bacteria	Sulfate is reduced to H_2S	3-8 hrs
Methane-forming bacteria	Production of methane in the anaerobic digester	3–30 days

The conversion of volatile solids (VS) to biogas in an anaerobic digester is controlled by HRT. It determines the rate and extent of methane production. Increase in retention time >12 days does not significantly contribute to increased destruction of VS. The rate of digestion of sludge varies from season to season, being a function of temperature. The rate of anaerobic digestion of sludge and methane production is proportional to digester temperature.

It has been noted in the above procedure that the following five parameters determine process configuration of the digesters.

Process configuration

Batch or continuous: The batch system is simplest, where the waste is added to the digester at the beginning and sealed for the duration of the process. Typically, biogas production forms a normal distribution pattern. Therefore, the operator can determine when the process of digestion has been completed. However, it suffers from severe odor problem during emptying cycles[1-5].

In the continuous process, which is common, waste is added in either stages or continuously, the end products are removed periodically or continuously, resulting in a continuous production of biogas. Upflow anaerobic sludge blanket (UASB), Expanded granular sludge bed (EGSB) and Internal circulation (IC) digesters belong to this category.

Temperature: Recurring problems of maintenance of optimum/uniform temperature of the digester needs priority attention. Secondly, inadequate mixing creates localized pockets of variation in temperature. In case, the digester in run using thermophilic anaerobes, they adversely affect digester performance due to low bacterial growth, high endogenous death rate of other bacteria and consequently lack of microbial diversity usually witnessed in the mesophilic digesters. Therefore, relatively high residual values of VFAs are registered.

Solid contents: Typically, the digesters are designed to operate at either high solid content [total suspended solids (TSS) greater than 20 %] or low solid content (where TSS is less than 15 %). For high solid digesters, land requirement is less due to dense slurry and net lower volumes. It also requires more energy input to process the feedstock.

On the contrary, low solid digesters transport wastes using pumps that require significantly lower energy input, attain thorough circulation of waste matter and its intimate contact with bacterial population, providing higher output efficiency. However, they require larger land area than required by high solid digesters due to increase in volumes[1,6-9].

Complexity: A single stage (one phase) digester is one in which all biochemical reactions (hydrolysis, acidogenesis, acetogenesis and methanogenesis) occur within its sealed environment. While it offers benefit of lower construction cost, it commands less control on the reactions occurring within the digester. Since microbes involved in these reactions being different, their optimal pH being either acidic or alkaline and their physiological needs for better performance differ significantly, single-stage digesters invariably perform below optimal level, resulting into either less biogas production or less % methane in it.

To address the limitation of single stage digester, while substrate hydrolysis and acidogenesis could be carried out in one digester, acetogenesis and methanogenesis in another digester. This theme of separation of biochemical processes and their catalyzing microbial populations has given rise to the concept of two-stage digester. In a two-stage digester, digestion vessels are different and their environment is optimized to promote maximum output from their bacterial communities. Typically, hydrolysis and acidogenesis occur in the first digester. Acidogenic bacteria multiply rapidly than methanogenic bacteria and hence produce organic acids more quickly. Acetogenesis could be spread over both digesters. The digested material is then heated to required operational temperature (either mesophilic or thermophilic) prior to being pumped into a methanogenic digester. Methanogenic bacteria require optimum pH 7.2-8.0 and slightly higher temperature in order to optimize their performance. Thus, separation of conditions to suit the needs of respective microbial populations enables two-stage digesters to give superior performance as judged from higher output of biogas and its enhanced % methane.

Nutrients: There are significant differences in nutrient requirements between aerobes and anaerobes. Differences in critical nutrients emanate due to unique enzyme systems needed by methane-forming bacteria. In the conversion of acetate to methane, cobalt (Co), iron (Fe), nickel (Ni), sulfur (S), selenium (Se), tungsten (W) and molybdenum (Mo) are required. Additional micronutrients are barium (Ba), calcium (Ca), magnesium (Mg) and sodium (Na). Macronutrient requirements for anaerobic processes are much lower than the requirements for aerobic processes due to lower cell yield.

Nitrogen and phosphorus are made available to anaerobic processes as ammonical- nitrogen (NH_4^+) and orthophosphate (HPO_4^-). Their amount needed to satisfy acceptable digester performance can be determined, considering adequate residual concentrations of soluble nutrients in the digester effluent. Residual values of 5 mg/liter of NH_4^+ and 1–2 mg/liter of HPO_4^- are usually recommended. Absence of residual nutrients means that nutrients must be added. While for nitrogen addition, ammonium chloride, aqueous ammonia and urea may be used, for phosphorus addition, phosphate salts and phosphoric acid may be used. While some methanogens are able to fix N_2, some use the amino acid, alanine.

Nutrient requirements for anaerobic digesters vary as a function of OLR. Generally, COD:N:P of 1000:7:1 is used for high strength wastes and 350:7:1 for low strength wastes, respectively. The C/N value of at least 25:1 is suggested for optimal gas production. Nitrogen is approximately 12% and phosphorus 2 % of the dry weight of bacterial cells. Both N and P should not be limited in the digester.

Retention time (RT): If the waste is primarily soluble, short retention time (RT) is adequate for maximum treatment efficiency. However, solubilization of particulates being a relatively slow biochemical action[10] for a waste with high suspended solids, anaerobic fermentation by longer RT with aerobic microbial consortium permits optimal solubilization and subsequent methanogenesis accomplished under anaerobic conditions. Thus, through the use of innovative, high-rate reactor designs, anaerobic treatment can now challenge the cost of aerobic treatment for many soluble wastewater treatment applications.

If solid retention time (SRT) is short, size of methane-forming bacteria is reduced.

RT of a substrate in the digester is a function of i. its chemical nature, ii. one-stage or two-stage digestion, iii. amount and type of feedstock and iv. physiology of microbial communities (mesophiles/thermophiles).

In a single-stage mesophilic digester, RT could be 15-30 days or more depending upon % solid content, while in thermophilic digester; RT may be in the region of 10-14 days. In the plug-flow system, full degradation of the waste may not be achieved in this time-scale, due to which, the digestate is dark in colour and has intense odor, a reflection of high BOD/COD level.

In a two-stage mesophilic digester, RT could be 15-30 days, with ample scope for its reduction under thermophilic conditions. In mesophilic UASB digesters, HRT may vary from 1-24 hours and solid retention times up to 90 days. In this manner, UASB system is able to separate solid on the basis of HRT with the utilization of a sludge blanket.

Continuous digesters have mechanical or hydraulic devices, depending on the level of solids, to mix them with the consortium of bacteria to allow excess material to be continuously digested by maintaining reasonably constant volume of input as well as output from the digesters[2].

Mass transfer consideration: Mass transfer into biomass occurs rapidly when i. bio-particle surface: volume ratio is high, ii. bio-particle diameter/bio-film thickness is less and iii. liquid phase.

After reviewing above factors which determined digester performance, it is equally necessary to find out the causes which lead to change in operational conditions and its efficiency.

Causes for changes in operational conditions in digesters

Of the total microbial population, approximately 80 % are facultative anaerobes, producing a variety of acids, alcohols, CO_2 and H_2 from carbohydrates, lipids and proteins. Facultative anaerobes (oxygen- tolerant species) and obligate anaerobes (oxygen – intolerant species) change operational conditions, which in turn result in changes in i. dominant bacteria and ii. concentration of acids/alcohols.

Since methanogenesis is catalyzed efficiently in defined range of oxidation-reduction potential (ORP), it is necessary to familiarize with method of ORP estimation and factors deviating it from optimum.

Method of ORP estimation

ORP of wastewater or sludge can be obtained by using a pH-meter, with a milli-volt scale and an ORP probe. ORP is an indicator of the capacity of molecules in wastewater or sludge to release or gain electrons (oxidation or reduction, respectively). At values i. less than -100 mV, mixed acids and alcohol formation may occur, ii. less than -200 mV, methane production may start and iii. less than -300mV, growth of methane-forming bacteria does not occur.

Conclusion

Over the years concerted efforts have evolved practical guidelines which could be metamorphosed into an operating procedure to run the biogas plant efficiently. Critical analysis of operational biogas plants has revealed that either right operating procedure was not in place or personnel manning these plants were not sufficiently trained to operate them efficiently. Unawareness or unidentified fear of handling anaerobic digester should be removed first for its successful operation. While the biochemical reactions inside the digester are complex, concurrent and if not regulated, they become counterproductive resulting into souring or shut down of the digester. For this purpose, detailed procedure is given by focusing underlying principals which regulate biogas output. Nutrient requirements for anaerobic digesters vary as a function of OLR. Finally, factors affecting digester performance are summarize so that maximum productivity of biogas could be produced, leaving slight BOD/COD in the effluent to be used as organic manure without defying the standards set by State Pollution Control Board. For the sake of totality, method of ORP estimation is given, since its narrow and critical range determines success or failure of anaerobic digestion.

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