35: Basic Generator Types

Probably the single most basic aspect of generator design is flow. How does the slurry move through the generator? There are several major types of generators, based on their different flow characteristics:

1. Continuous-feed high-rate mixed (high-rate)
2. Continuous-feed, intermittently mixed (moderate rate)
3. Continuous-feed, unmixed (plug flow)
4. Batch-feed, mixed or unmixed
5. Hybrid

35.1 Continuous-Feed, High-Rate Mixed

Almost all large-scale manure substrate biogas generators are *continuous-feed, high-rate mixed generators*. As you no doubt remember, with a continuous-feed generator, its size depends on the HRT, and the volume of the daily load. If we feed a generator a liter each day and each liter stays in it about 10 days (a 10-day HRT), the generator will have to be at least 10 liters in volume. Since the rate of biogas evolution depends mainly on the temperature, and since the biogas is evolved faster at first and then ever more slowly, the idea here is to get as much biogas as possible out of each cubic meter of generator, which means optimum temperature (35°C, 95°F) and short (10-20 day) retention times.

In practical fact though, while a smaller, continuous-feed, high-rate generator will cost less than a larger generator of another type, it may require more supplementary equipment (for heating, agitation, etc.) and careful watching; this kind of generation can be more unstable than other kinds. This may cause the cost of the two types, geared to the same job, to be roughly equal.

High-rate generators— another name for continuous-feed, high-rate mixed generators— must be fed substrates which mix easily with water, and agitation will be difficult at or above 10% solids, depending to some degree on the percentage of VS in the substrate. High-rate generators generally avoid the problem of scum accumulation. These generators require an agitation system, a heating system, a pumping system for the slurry, and any of several kinds of monitoring systems, to keep track of the health of the biogas process.

A high-rate generator operates on a tightly knit balance of factors, including temperature, loading rate, percentage of solids, retention time, and sometimes the concentration of ammonia. Changes in these factors can upset the high-rate biogas process, and so care must be taken with high-rate generators to maintain a constant temperature, to not allow the load rate, percentage of solids, or concentration of ammonia to increase, nor to allow the retention time to decrease.

High-rate generators are not necessarily better or worse than other designs, but the short retention time for the slurry means that anywhere from 40% to 60% of the biogas which it is possible to generate from that slurry remains in it, and is not evolved. Of course, the last 40% to 60% is also harder to get, because it takes much longer to be evolved than the initial gas spurt. (For further details, see Appendix 4: Math of Gas Production, p. 230.

"Waste" is a relative concept. The whole economic scheme of high-rate generators is based on whether we waste space (cost), or waste potential biogas (benefit). Certainly the high-rate generator is among the best available for biogas production from intensively produced animal wastes, but it is less suitable for the small scale situation. Chapter 45: Design Process, p. 186, and Appendix 4: Math of Gas Production, p. 230, can help you make a sound decision, if you want a high-rate generator, about what trade-offs you may wish to make between retention time and volume on the one hand and rate and amount of biogas evolution on the other.

Among the alternative kinds of high-rate generators available, one which moves into the upper echelons of technology is the fixed-film generator. This is a generator which makes use of the fact that the biogas bacteria like to stick to solid surfaces. The generator is essentially a collection of tubes, through which the slurry is pumped. The inside surfaces of the tubes, once generation is well established, become coated with populations of bacteria, and these "react" with the passing slurry.

35.2 Continuous-Feed, Intermittently Mixed

These words describe a large number of different generators, as for example, many of the designs of Ram Bux Singh. These generators have less sophisticated agitation and pumping system designs, and use less energy. Many designs call for a gravity feed/displacement flow system, where slurry enters by gravity and displaces a portion of the digested effluent.

Because these generators usually have a longer HRT, they are larger than high-rate generators, and not as easily upset by changes in parameters. However, they are sometimes plagued by scum and sediment problems which can easily shut down a generator. (Any intermittently mixed design which fails to make a provision for scum and sediment accumulation will prove to be a costly experiment.)

Most municipal sewage digesters are of this type, with 30-day HRTs. Some municipal digesters have two separate tanks which can be used either one after the other, or as two separate, single-stage generators.

For larger generators, this is an excellent means of insuring process stability— or a continuing supply of biogas— if half of the generator should have to be shut down.

There is no overwhelming biological reason why a continuous-feed, intermittently mixed generator cannot operate with a greater-than-10%-solids-content slurry, although there may be mechanical reasons, depending mainly on the type of input (feeding) system— whether by gravity or pump, or some other method.

A further example of a partially mixed design is found further on in this book, where a continuous-fed design is shown that is reportedly capable of operating on plant waste substrates.

35.3 Continuous-Feed, Unmixed

These generators, usually long affairs which move slurry from one end to the other by gravity displacement, often have no auxiliary systems except for heating. The long ones are also known as plug-flow digesters, because they tend to operate like the digestive systems in our bodies, where small amounts of food move (without much mixing, or in other words, as "plugs" or discrete lumps) through a digestive process.

L. John Fry seems fond of horizontal, plug-flow, unmixed generators. His large South African "displacement digester" was of this kind, and the small generators described in *Methane Digesters for Fuel Gas and Fertilizer* are of this sort.

It is a still simpler design than the two previously described, and it may be suitable for lower cost farm-sized generators (albeit with higher labor requirements), as amply demonstrated by Mr. Fry. Some provision must be made for scum accumulation besides occasional cleanout.

Another low-cost alternative which has stirred up much talk in biogas circles is the Chinese generator. This is an underground design, and the ultimate in simplicity. It is not, however, the ultimate in productivity. Whereas your average high-rate-generator will give one volume of biogas per volume of generator per day, the Chinese design will only give 0.2 volumes of biogas per volume of generator per day. Radical chic aside, these will not work well in cold climates. Construction starts with a circular wall. Then the inside is filled with earth and a dome with a manhole in the middle is built on the mounded earth. Finally the dirt inside is dug out and carried away through the manhole, and the floor is poured. The manhole is covered with a concrete plate, and the seam is sealed with moist clay. The clay is kept moist with a pool of water, and sometimes plants are grown in this small pool. It is claimed that there are more than seven million of these generators in existence, making this the world's most popular design. Further information can be gotten from the book *A Chinese Biogas Manual*. See the Bibliography for full information.

Where labor costs make the Chinese design impractical, another noteworthy plug-flow design suitable for the temperate and equatorial regions is the trench generator. This generator is constructed the way you might expect from the description. A long trench is dug in flat, gently sloping ground. Often, no provision is made for heating except what is inherent in the generator itself— that is, it may collect solar energy. The trench is lined with what is, essentially, a plastic bag. While the plastic provides leak-proofing, mechanical support for the generator is provided either by the earth (e.g., essentially the generator is underground) or by a reinforced plywood structure. Books on concrete form building will give you some idea of the stresses you are likely to encounter in a plywood support wall, and these books should also describe ways of counter-stressing the wall to resist the force of the liquid. The bag or generator tube could be made out of 15-20 mil or heavier sheet plastic, heat sealed, or glued. All dimensions would depend on:

1. the volume of substrate (a mix-well);
2. the percentage of solids (below 10%); and
3. the retention time (30 to 60 days).

More research should be done on this, as it may prove a very inexpensive means of construction for a large-scale generator. Climate (ambient temperature) and type of plastic (for UV degradation resistance) would much affect the economics of such a generator.

Among the kinds of plastic being used for the bags, the two most popular kinds are hypalon and butyl rubber. The various kinds of polyethylene, if they are kept away from sunlight (which will eat them up) can be used above the generator bottom as a gas collector. The use of this option creates a two-material bag, with the bottom of hypalon and the top of the more pedestrian polyethylene. William Jewell, who shows up in various places in this book (and in the Bibliography), is one of the leading designer-testers of this kind of digester.

35.4 Batch-Feed, Mixed or Unmixed

The simplest generators are batch-fed generators. They are filled up, they generate, they are emptied. The chief advantage of a batch-fed generator is its low cost, simplicity of design and construction, and its ability to operate well regardless of the substrate being fed. Batch-fed generators can even decompose twigs and unshredded leaves (given enough time), as you will see.

The chief disadvantages of a batch-fed generator? It generally requires manual labor to fill and empty, and it will only generate gas irregularly. The reason for this irregular gas production is that the whole batch of slurry is going through the biogas process at one time. After starting, biogas production will build to a peak, and at first sharply, then more gradually, diminish until it is barely perceptible. Sometimes gas production will continue for a very long time (years) at low levels.

To partially overcome these disadvantages, batch-fed generators can be grouped, so, for example, that while one is being filled, several are generating, and one or more are ready to be emptied. The modular batch-fed generator described in this book calls for small modules, made of 55-gallon drums, which are set up in groups of 1 to 20 or more. These modules can cost less than $4 each to build, which compares favorably (at about 50 cents a cubic foot) with larger generators, many of which may cost 4 or 5 dollars a cubic foot.

35.5 Hybrid Generator

A hybrid is the offspring of two animals or plants of different varieties. Now obviously, the term is not used to mean exactly that here. But the generator described by this term is a mix of two basic generator types— batch and continuous— and of the two stages of biogas generation, acid digestion and gas digestion. Briefly, for the idea will receive more attention in the next Section, a hybrid generator has two stages, the stage where acid formation (or digestion) takes place, and the stage where methane formation (or digestion) takes place.

In the particular design we will discuss, substrate materials which must generally be used in a batch generator are loaded into the acid digestion stage. This stage of the generator is unheated. In it, the AF bacteria (acid formers, less affected by cold than the MF bacteria), break the complex organic molecules down into soluble molecules such as fatty acids— the main food source for the methane-forming bacteria.

These soluble molecules are pumped into the second stage and transformed by MF bacteria into high quality biogas. The second stage is, of course, heated.

So, a large cold batch-fed first stage produces fatty acids for a smaller, heated, continuously fed second stage— a hybrid generator. One principal advantage to this is the fact that less heat is required for the whole operation, resulting in a savings in energy.

A hybrid design need not be used only with a batch-loaded first stage. Mix-well substrates could be used, and the first and second stage continuously loaded. HRT would be the sum of the retention time for both stages, and loading rate would be a function of the total volume of both stages.

Research that has been done suggests that the continuous-fed hybrid design is very process-stable.

Terms

Hybrid Generator: Generator in which the acid-forming and methane-forming stages are separated.

Moderate rate: Laid back.

Plug flow: A generator in which the flow occurs in such a way that each day's slurry addition does not mix too much with any other day's addition.

Trench generator: Simple plug-flow generator built in a trench.

Questions, Problems (none)