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Development of a Small Scale Anaerobic Digester for Demonstration and Testing

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Abstract

This paper will document the design decisions involved with the construction of a small (2.4 m^3), trailer-mounted anaerobic digester. The digester represents a complete mixed design, operating in the mesophilic temperature range. The digester has two main purposes: it will be used to conduct "recipe" experiments and it will be used for display at trade shows and other venues – in an effort to explain the process of anaerobic digestion of (mainly) agricultural materials. Viewing ports make it easy to see what is happening inside the digester. The paper describes the development process and gives results of early testing.

Introduction

A project to build and demonstrate a portable anaerobic digester was initiated with the support of the Fresh Vegetable Growers of Ontario (FVGO). The digester was considered to be an important tool in assisting Ontario growers decide if digestion had a place in their operations.

Traditionally, the majority of the revenue vegetable growers receive is from the sale of their crop to the fresh or processing use markets. Because competition from both domestic and foreign producers keeps the price of vegetable crops low, it makes sense to consider if an additional source of revenue might available from the waste material generated during the growing season. For example, up to 40% of a sweet potato crop may be unsuitable for fresh market sales due to visual appearance or size. Some of these "seconds" may be sold to the food processing industry, but a better use may be as a feedstock for the production of biogas via the process of anaerobic digestion (or bio-digestion). Potential feedstocks include crucifer crops, root, bulb and leafy vegetables, sweet potato, field tomatoes, or any spoiled or low-quality vegetable matter.

Anaerobic digestion involves the microbial breakdown of organic compounds in the absence of oxygen that results in the production of a biogas consisting primarily of methane and carbon dioxide. Biogas can be converted into electrical energy and heat through combustion in a modified generator, or burned directly to produce heat. In Ontario, on-farm use of anaerobic digesters is usually associated with the treatment of livestock manure (i.e. manure is the primary feedstock) although the use of forage or field crops has been quite successful in Europe.

The establishment of large scale anaerobic digesters has the potential to positively impact rural development in several ways. Economically, these units provide a new opportunity for previously unmarketable waste horticultural products, with revenue being generated through energy production, possible tipping fees for accepting off farm wastes (e.g. food processing waste), and the production of a high quality effluent. This nutrient-rich effluent can reduce the use of commercial fertilizers. Furthermore, anaerobic digestion of waste material helps reduce the levels of pathogens and weed seeds, and reduces odours compared to other traditional waste handling methods.

Objectives

Funding was secured and a project was started to design, build and operate a small anaerobic digester. The project had two main objectives:

1. To assemble a portable anaerobic digester of sufficient size to provide meaningful biogas production results, but small enough to allow for rapid assessment of different vegetable waste feedstocks; and
2. To use the unit as an educational tool at agricultural events such as Canada's Outdoor Farm Show.

In the longer term, the system would be used to:

- Assess the suitability of different vegetable wastes as feedstocks for the production of biogas.

- Determine the handling, processing and storage requirements for different feedstocks.
- Determine the optimum conditions to maximize biogas production, including pH, ammonia concentration, feedstock size, needed micronutrients, temperature, and retention time.
- Collect data to assess the economic potential of using vegetable wastes as energy feedstocks.
- Measure the nutrient quality of the effluent generated from different input crops

Design Considerations

In early 2007, a study team began setting out the design criteria for the project. The team consisted of university and government experts and a representative of the engineering firm selected to deliver the end product – i.e. CEM Engineering, Canadian distributor for PlanET Biogas, a large German Biogas company. The main challenge faced by the team was the short time frame available to complete the entire project, once the funding was in place. Once the final design was agreed upon, construction of the unit went smoothly.

Features Deemed Essential

The following features were considered to be essential in the design of the digester:

- Portable – mounted on a trailer for easy movement to trade shows, etc.;
- Viewable – equipped with viewing windows for clear views of the digesting liquids;
- Able to run off a standard 115 volt electrical service;
- Incorporate a stirring device, complete with automatic controls;
- Incorporate a system to introduce both liquid and solid inputs;
- Constructed using standard parts, as much as possible, to facilitate repairs and maintenance;
- Safe – complying with all relevant safety standards; and
- Affordable – completed within the $80,000 budget.

Features Deemed Desirable

Certain features were desirable but were open for discussion, depending on priorities and budget. Following is a brief discussion of several of these features:

- Flare or generator? For the small quantity of gas produced (due to the small size), would a flare be more feasible than a small electrical generator? A flare would need to be approved for use and may need a system to ensure it stays lit in possible breezy conditions.
- Gas analysis – A system was needed that would measure volume of gas and analyze the gas stream for concentrations of methane and carbon dioxide.
- Liquid sampling – A system was needed that would allow for easy sampling of liquids.

- Sand removal – There was discussion of incorporating a system of removing sand, in the event that it began to accumulate (i.e. due to use of sand bedding for dairy manure, or due to soil attached to vegetable wastes).

Final Design Features

Figure 1 shows the completed version of the digester. The unit includes a hot-water heating system, a mixer, gas storage, washer for the windows, bottom drain and Plexiglas windows. The trailer has a low floor for better visibility and a removable canvas cover for transportation (see Figure 2). The dry feeder is a simple design with one feeding auger and attached hopper. The auger is driven by a small motor.

Figure 1 Completed anaerobic digester

Dimensions

The digester tank is constructed of HDPE. The inside diameter is 152 cm and the depth (floor to the top of wall) is 129.5 cm. The flexible domed cover extends to 35 cm above the top of the wall. The total volume of the digester, including the domed cover, is 2.7 m^3. This includes a liquid volume of approximately 1.7 m^3, which is about 62% of the total volume. The tank walls are not insulated, so cold-weather use will be limited, unless extra insulation is added.

Figure 2 System prepared for transport

Mixer

Rather than use a specially constructed paddle mixer, a standard mixer was purchased (see Figure 3). Currently the mixer is set to run for 30 seconds once every 30 minutes – the automatic setting can be adjusted. In addition, the mixer is run before and during the removal or addition of material.


Figure 3 Mixer installed in digester

Materials Handling – Inputs and Outputs

Dry materials can be added to the digester via a 5 cm diameter auger driven by a small electric motor. The inclined auger is installed in a stainless steel hopper (see Figure 4). In the interests of safety, a lid is fitted onto the hopper when not in use. The system was designed so that the auger could operate on a timer.

Liquids may be pumped into the digester through a 19 mm hose connection passing through one of the windows. Alternatively, liquids may be pumped through the 75 mm drain hose at the bottom of the digester wall – the same fitting used for the removal of digestate.

Figure 4 Inclined auger and stainless steel hopper

Figure 5 Shredded sweet potatoes and recycled digestate being added through the auger

Heating System

The system is set to run in the mesophilic range (target is 37^{o}C). An electric water heater (see Figure 6) maintains the desired temperature. Warm water is circulated through heating tubes lining the lower half of the inside of the digester (as shown in Figure 3). Currently, the temperature setting for this warmed water is made manually, based on monitoring the temperature of the digester contents.

Figure 6 End compartment housing the water heater and electrical panel - wired for 115 and 230 V

Gas Monitoring

The unit is equipped with a gas flow meter and a gas analyzer (see Figure 7). The flow meter totals the gas production. The analyzer (ProNova SSM 6000) determines the concentrations of methane, oxygen and hydrogen sulfide. If hydrogen sulfide (H_2S) levels are too high for the intended use, small amounts of air can be pumped into the system to remove the H_2S. Currently, gas is flared using a Bunsen burner. A pressure relief valve prevents over-pressurization of the digester.

Figure 7 Equipment for measuring gas flow rate and volume and for analysis of methane, oxygen and hydrogen sulfide

Viewing ports

Six Plexiglas windows make it very convenient to witness the activity on the liquid surface inside the digester (Figure 1). If too much condensation accumulates on the inner surface of the windows, water can be pumped through a nozzle in the top of the digester to spray the windows clean (See Figure 8). If the transparency of the panels fades over time, new panels can easily be inserted. Figure 9 shows actively digesting liquid, as viewed through one of the windows.

Figure 8 Internal rinsing system to keep viewing windows clean

Figure 9 View through one of the windows - digesting liquids

Performance of System

The system was completed in the fall of 2007 and preliminary tests were run in November and December, as well as follow-up tests in the spring of 2008. Over a one month period in winter, a mix of swine manure and sugar beets produced only 224 L methane per kg VS. Almost certainly, this value underestimated the true potential, as there were problems in maintaining digester temperature during this trial. Methane represented 56.7% of the total biogas production. Spring-time trials gave better results. Following are observations made during the initial start-up phase for the new digester:

- The equipment was demonstrated at a farm trade show. It performed well and looked professionally constructed – it proved to be a good demonstration unit.
- During the subsequent test period, several leaks were detected at the roof-to-wall interface, around some of the windows and on parts of the gas lines. These were significant leaks that needed to be sealed.
- Temperature control in the winter was a challenge, even with additional blanket insulation around the digester. Unacceptable digester temperature fluctuations resulted. This unit appears to be best suited to operation where the ambient temperature can be maintained above approximately 10^oC.
- Although liquids can be added through the drain port, it proved difficult to control the volume of inputs. The large diameter input hose has too great a volume compared to the relatively small amounts that need to be added. Using the auger has proven to be a good alternate method.
- The 50 mm dry feed auger appears to be too small for some of the solids for which it was conceived. In addition, the hopper “V” angle is too steep, resulting in the bridging of solids. Materials such as corn silage, ground sugar beets or ground sweet potatoes will not go through the auger without extra liquid.
- The trailer deck is 3.7 m x 2.0 m. While it holds the desired equipment and is easy to step onto (one of the design criteria - for demonstrations), the compromise is that it is rather cramped for working upon.
- The digester heating system should have been more automated. This might be accomplished with a thermostat that controls the operation of the water heater. This feature will likely be added in order to reduce temperature fluctuations.
- Extra gas storage is needed. The expandable domed cover cannot hold the gas that is produced overnight. This is not so much a design issue as a basic necessity of the overall system.
- Moisture in the gas can cause an accumulation of condensation in the gas lines, and lead to freezing of valves in cold weather. The system would benefit from a system to remove moisture from the biogas.

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