

Design of an Anaerobic Waste Digester

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ABSTRACT

Some important characteristics of a sustainable waste management program include the recovery of materials and energy from generated wastes and the stabilization of residues. One of the alternative sources of energy, which may compensate for the shortage of conventional fuel in the future, is naturally-produced biodegradable waste products (biogas). Biogas is the by-product of anaerobic decomposition of organic matter by micro-organisms, mainly bacteria. The process is also referred to as anaerobic digestion. Biogas contains about 60% methane (CH₄) and 40% carbon-dioxide (CO₂). Thus, the anaerobic digester has been widely used in the production of biogas on a worldwide scale. The results obtained from the experiments in the scientific literature have varied, depending on the substrate input utilized, the conditions under which biogas production is conducted, and the design of the anaerobic digester. Given the same input requirement, the design of the digester may cause a wide variability of results. Thus, the designs of anaerobic digesters are of prime importance to the biogas community. This paper presents the design of a simple anaerobic digester, which can generate 200 liters of cooking, gas (methane) per day. The input material is swine waste, which is readily available on Nigerian farms. This paper is intended to guide researchers in the choice of appropriate design characteristics in order to achieve optimum results in biogas production.

(Keywords: biogas, digester, anaerobic, energy, biofuel, alternative fuel, methane)

INTRODUCTION

Important characteristics of sustainable waste management includes the recovery of materials and energy from the waste generated and the stabilization of residues. In the not-too-distant

future, many countries will be facing another problem due to a shortage of fossil fuels. One of the alternative sources of energy, which may in the future compensate for the shortage of conventional fuels, is biogas which is naturally produced from biodegradable waste. (Hvid et al, 1998). Biogas is one of the by-products of anaerobic decomposition of organic matter by micro-organisms, mainly bacteria, a process also referred to as anaerobic digestion. It consists of about two-thirds methane (CH₄) and one-third carbon dioxide (CO₂). It is known as land fill gas (LFG) when produced from organic domestic refuse or industrial waste; or as sewage gas when produced from sewage or animal dung (Xuereb, 1997).

Biomass is considered as organic matter derived from plants or animals (Rozdilsky, 1998). Biomass energy is the use of the stored solar energy inherent in the organic molecules that make up living things. Biomass can be converted to energy and useful products through biochemical and thermo-chemical processes. These processes are combustion, dry chemical process, and aqueous processes. In other words, biomass can be burned, converted to a gas, or changed to a liquid fuel (Brower, 1992). The main focus in this work is on a specific type of aqueous process known as anaerobic digestion. In farm-based anaerobic digestion, the swine waste is bio-chemically converted to a gas and then this gas is used as a fuel for generating energy (Koelsch, 1990). The objective of this work was to design a simple anaerobic digester to handle swine waste generating 200 liters of methane (cooking) gas per day.

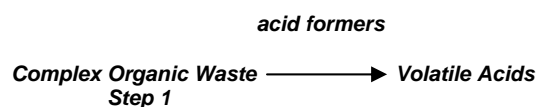
PRINCIPALS INVOLVED IN ANAEROBIC DIGESTION

Anaerobic digestion can be described as a two-stage process accomplished by bacteria which

flows in the absence of oxygen. A description of these two stages follows:

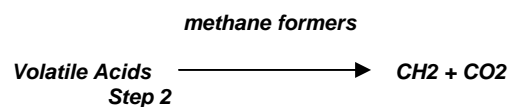
Acidification

Acid forming bacteria break complex organic wastes down into volatile fatty acids. Proteins are broken down into amino acids and further into volatile fatty acid. Carbohydrates are broken down into simple sugar and then into volatile fatty acids. Fats and oils are broken down to long chain fatty acids and then to volatile fatty acids. Acetogenic bacteria use the volatile fatty acids and form acetic, propionic, and lactic acids. In addition, hydrogen and carbon dioxide gas can be released by acetogenic bacteria .



Methane Production

Methane forming bacteria (methanogens) uses acids formed in stage 1 to produce methane. Other bacteria use hydrogen and carbon dioxide in stage 1 to form methane.



These two types of bacteria can become out of balance in a poorly maintained environment. If the digester situation becomes too acidic (indicated by a pH less than 7) then the methanogen bacteria population is low. However, if the digester situation is too basic, then acetogenic bacteria population is too low. Bacteria tend to adhere to solids in the solution. Because of this, many digesters used to process organic waste stir these solutions periodically to ensure a mixture of bacteria throughout the solution.

Temperature

The anaerobic digestion processes is carried out by a delicately balanced population of various bacteria. These bacteria can be very sensitive to changes in their environment. Temperature is a prime example. It has been determined that 35 C is an ideal temperature for anaerobic digestions. As the temperature increases some bacteria begin to die, once again biogas production decreases. Insulation heat exchanges, heating elements, water baths, and steam injector are all means which have been used of control digester temperature. Temperature counting is an important consideration when designing digesters.

Alkalinity and pH

Alkalinity is a measure of the amount of carbonate in a solution. Acidity or basicity of a solution is indicated by pH. Alkalinity is important because as acid is added to solution, carbonates will contribute hydroxide ions which tend to neutralize the acid. This is known as a buffering effect or alkalinity. Bacteria flourishes over a narrow range of pH of 6.5 to 8.0. As the acid forming bacteria produce acid, methane-forming bacteria utilize the acid and maintain neutral pH. Since the reaction rate involving the acid forming bacteria proceeds much faster than the reaction involving methanogens, a larger population of methanogens must be nurtured and maintained.

Feeding the Digester

Digesters are usually fed based upon three bacteria, volatile solids, hydraulic retention time, and carbon – nitrogen ratio.

1. Volatile solid (VS)

Is a measure of the amount of organic matter in a material. If too much organic matter is added the acid producing bacteria can convert the organic matter to acid, before the methanogen can use the acid. The resulting acid accumulations cause the digester to fail because the methanogenic bacteria cannot survive in highly acidic condition.

2. Hydraulic retention time (HRT)

This is a measure of the time the digester liquid remains in the digester. It is crucial because if the feed does not stay in the reactor long enough for the entire digestion process to take place, biogas will not be produced.

3. Carbon- nitrogen ratio

Just as a balanced diet contributes to a healthy person, a balanced C-N ratio helps maintain a stable, healthy bacteria population. Anaerobic bacteria commonly use carbon as an energy source for growth and nitrogen to build cell structure. The bacteria most efficiently utilize feeds which have a carbon –nitrogen ratio of approximately 30:1.

METHODOLOGY

Design Assumptions

- Complete mix reactor
- Hydraulic retention time (HRT) =12.5 days
- Influent total solid = 8% dry
- Refractory fraction R= 6% of TS
- Degradation coefficient k = 0.15
- Digester operating temperature = 350C
- Wet manure density = 1.0

- Biogas production = 0.3v/v-day @ 60% CH₄
- Methane production per 50kg animal waste = 58.10 liters
- Heater size to supply 2,000KJ/hr/m³ of digester liquid volume.

Total Amount and Volume of Waste

The volume produced per 50kg of animal waste is 58.10 liters. Therefore, Animal waste required to produced 200 liters of CH₄/day = (200x50)/58.1 = 172.12 kg.

If 175 kg/day (wet) is chosen, then total mummies = 175kg/day (wet)

Digester feed rate = 50/0.08 = 625 kg/day

Dilution water required = 625 – 175 = 450kg/day

Manure: Water dilution ratio = 6250/2750 = 625/450 = 1.39 = 1 : 0.72

Digester Volume

$V = \text{HRT} \times a = 12.5 \text{ days} \times 625 \text{ kg/day} \times 1 \text{ litre/kg} = 7812.5 \text{ litres}$

The v = 7,820 litres. Choose 8m³
where, V = volume and Q = flow rate

Volume in Organic Loading Rate

$\text{VOLR} = (50 \text{ kg TS/day} \times 0.82 \text{ VS/TS}) / 7.82 \text{ m}^3 = 5.2 \text{ kg VS/m}^3 \text{ day}$

Effluent Volatile Solid Concentration

$$S_e = \frac{((1-R) S_o + R_s)}{(KQ+1)}$$

$$= \frac{(1-0.06) 80 \text{ gTS/l} \times 0.82 \text{ VS/TS} + 0.06 (80 \text{ gTS/l} \times 0.82 \text{ VS/TS})}{((0.25 \text{ day}^{-1} \times 12.5 \text{ day}) + 1)}$$

where S_o = Influent TVS mg/l, K = a dimension kinetic parameter

For definite trainers, K = 0.6 ± 0.051 (S_o), R = refractory fraction expressed as a decimal

Therefore S_e = 18.9gVS/litre

Volatile Solid Conversion Efficiencies

$$\frac{(S_o - S_e \times 100\%)}{S_o} = \frac{(80 \text{ gTS/l} \times 0.82 \text{ VS/TS}) - 18.9 \text{ gVS/l}}{(80 \text{ gTS/L} \times 0.82 \text{ VS/TS})} = 0.7118 = 71.2\%$$

∴ < 71%

- Gas production per 50kg animal waste 89.34 liters

Volumetric Methane Production

Methane volume =

$$\frac{0.35HC + 14X * COD * \Delta VCS}{g(COD) * VS * TS} = 250 \text{ l CH}_4/\text{day @ stp.}$$

where, X = 0.71 (VS conversion)

The digester height (H) = 1.25 m is chosen.
Diameter of Circular Tank for Chosen Height

$$V = \frac{\pi d^2}{4}$$

$$\text{This means that } d^2 = \frac{4 \times 8}{3.142 \times 1.25} = 8.149$$

Thus, d = 2.85m. The, use d = 2.9m.

Shaft Design Assumptions:

- Speed of revolution of shaft, N = 300 rpm
- Length of shaft, L = 0.875m
- Weight of steel shaft, W = 50kg/m
- Modulus of Elasticity, E = 207GN/m²
- Modulus of rigidity, G = 79.6 GN/m²
- Yield strength of steel, S_y = 275MN/M²
- Factor of safety, N = 3.0
- Mass of paddle attached to shaft = 19.6N
- Constant depending upon and conditions, C=1.

i. Power required to mix digester content

Horse power (hp) = 0.185 X % solids x liquid capacity

In watts: 1hp = 0.746KW

Therefore 118.4hp = 8.8KW

ii. Torsional Moment (Mt)

$$M_t = 60P = 608.8 \times 103 = 280 \text{ Nm}$$

iii. Maximum Bending Moment (Mb) of Shaft

Where W₁

W₂ = weight attached to shaft

$$\dot{O}M_b = 0 = RAL = W1 L/2$$

Maximum bending occurs at $x = \frac{1}{2}$

iv. Shaft Diameter

$$d^{3_{crit}} = \frac{16}{\pi S_s} \sqrt{(KM_b) + (k_1 M_1)^2} =$$

$$\frac{16}{3.142 \times 40 \times 10^6} \sqrt{[(1 \times 0.21)^2 + (1.2 \times 0.28)^2] \times 10^3}$$

Critical and Safe Loads

$$\frac{L}{K} = \sqrt{\frac{2C\pi^2 E}{S_y}} = 122$$

$$\frac{L}{K} = \frac{L}{\sqrt{\frac{I}{A}}} = 45.45$$

Thus since $45.45 < 122$. (Johnson's formula is applicable), then (Shigley, 2000):

$$F_{cr} = S_y A \frac{1 - S_y (L/K)^2}{4C\pi^2 E} = 1.19MN$$

However, the ratio $F_{cr}/N = 1.19/3 = 0.40MN$

CONCLUSIONS

Biogas burns well and hence can be considered as a virtually free renewable source of energy suitable for heating proposes or generation of electricity in many countries. Electricity generating plants running on LFG have power output ranging from 0.8MW to 3.7 MW, while those running on sewage gas have power outputs ranging from 250 Kw to 7.8 MW. The use of biogas should be encouraged because it is in line with one of the fundamental principles of waste management, to reuse while as the same time providing a cheap source of energy.

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