Increasing the Sustainability of Dairy Farms with Anaerobic Digestion

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Introduction

The Food and Agriculture Organization has predicted a 19% increase in global consumption of dairy products by 2050, largely due to a 46% increase in developing nations in Latin America, Eastern Africa, South Asia, East Asia, and Sub-Saharan Africa (Shine). This steep increase has begun to highlight the large amount of energy dairy farms need to operate. Most of the energy comes from grid-sourced electricity and natural gas, leading to numerous negative effects on the environment as well as negative financial impacts on dairy farmers as the price of energy increases.

To help combat these increasing energy costs more farmers have implemented anaerobic digesters. Anaerobic digestion creates an environment for bacteria to break down organic matter leaving behind biogas and digestate (EPA). This biogas mostly comprises methane (CH_4) and carbon dioxide (CO_2) which can be used as an energy source while the digestate is a nutrient rich fertilizer replacement. The complementary nature of inputs and outputs for both farms and anaerobic digesters allow the reaction to continue while generating energy and reducing waste.

Figure 1: Visual of anerobic digester in agricultural environment

Process Description

The process of anerobic digestion has four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis.

1. **Hydrolysis**
   - The bacteria release enzymes which separate the complex sugar, fat, and protein polymers into simple monomers which can be utilized by the acidogenic bacteria.
2. **Acidogenesis**
   - Simple molecules are turned into acid chains, called volatile fatty acids (VFAs) by acidogenic microorganisms.
   - This process is sensitive to pH values and the production speed and concentration of VFAs produced can vary depending on the pH of the system and the type of waste placed into the reactor.
3. **Acetogenesis**
   - Larger VFAs are converted into acetate ($C_{22}H_{33}O_{22}$-) and Hydrogen, so it may be used by methanogenic bacteria.
4. **Methanogenesis**
   - Methanogenic bacteria turn the intermediate molecules, hydrogen and acetate, into methane.
   - These bacteria are extremely sensitive to oxygen and will die within hours of exposure.

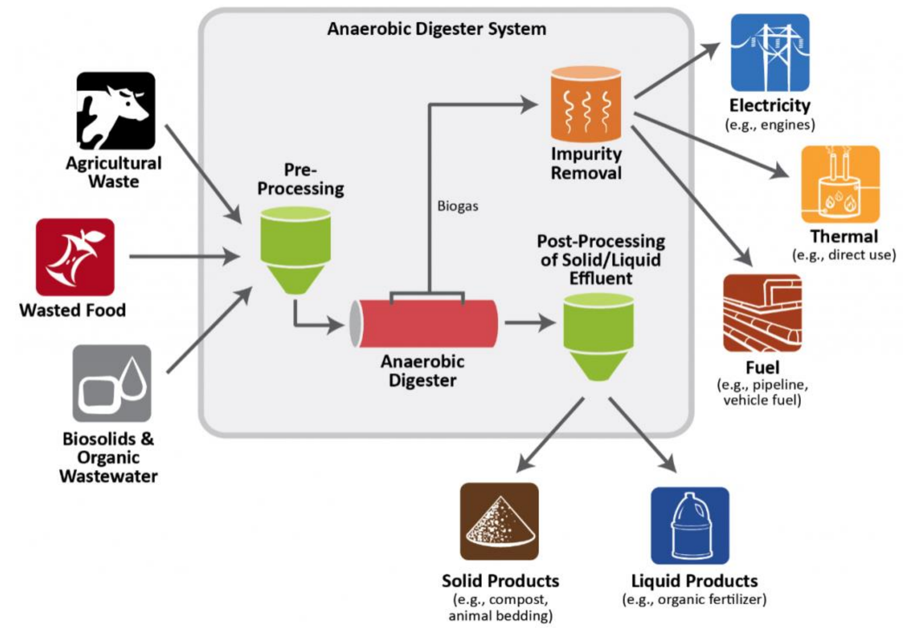

Figure 2: Simplified model of anaerobic digestion's reactants and products

Impacts on Ecosystem Services

Anaerobic digestion is an extremely sustainable process and has many benefits for farmers as well as others with excess waste and a need for energy. However, one aspect that does not receive as much attention is how it supports the ecosystems around it.

Anerobic digesters:

- Stabilize biosolids and effectively deactivate pathogens, viruses, parasites, and the pathogens that are sheltering antibiotic resistant genes.
- Convert nutrients from several types of waste into more accessible forms for these plants to use compared to raw manure, this increases the productivity and yield of the crops.
- Produce heat, electricity, and fuel helping farms depend less on fossil fuel energy.
- Provide an efficient outlet to remove waste and prevent pollution.

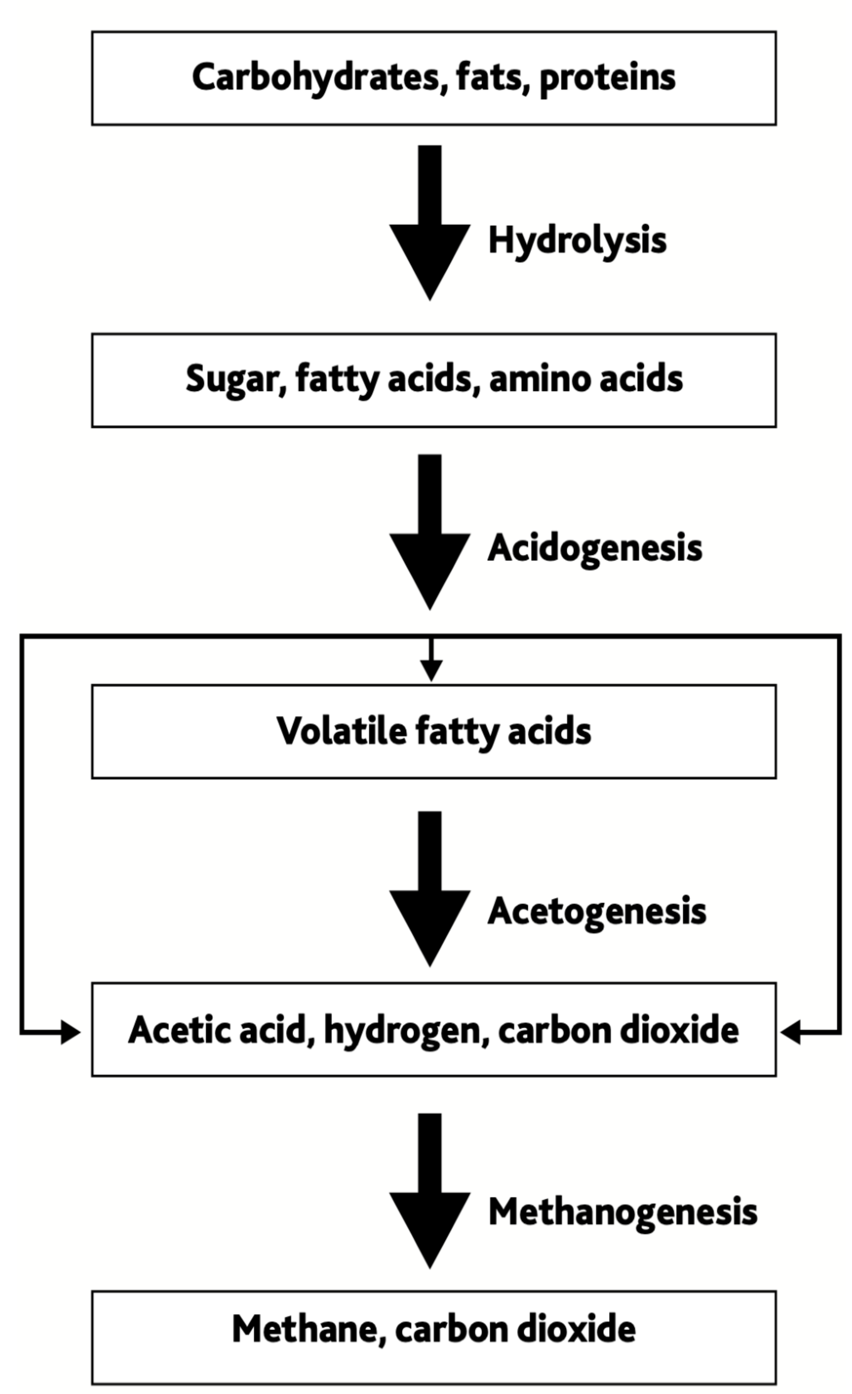

Figure 3: Diagram of the phases of anerobic digestion

Most Sensitive Unit

The consistency and regulation of the anaerobic digestor is the most important part of implementing an efficient system on a dairy farm. The consistency of the digestor relies on multiple variables:

- For the anaerobic digestor to produce enough output to be profitable, the farm must produce enough usable waste for the digestor. Specific research would need to be done on waste production and energy usage for each dairy farm to maximize energy output and minimize the payback period.
- Depending on the type of bacteria, the digestor must be kept at a certain temperature:
  - If using mesophilic organisms: 30°C to 38°C (Schnaars)
  - If using thermophilic organisms: 50°C and 60°C (Schnaars)
    - which produces more gas but must be kept at a higher temperature.
- Daily required maintenance by qualified operator:
  - Checking quality of biogas produced.
  - Maintaining the volatile acid to alkalinity ratio.
  - Performing necessary fixes to system failures such as clogged pipes or mechanical malfunctions (Schnaars).

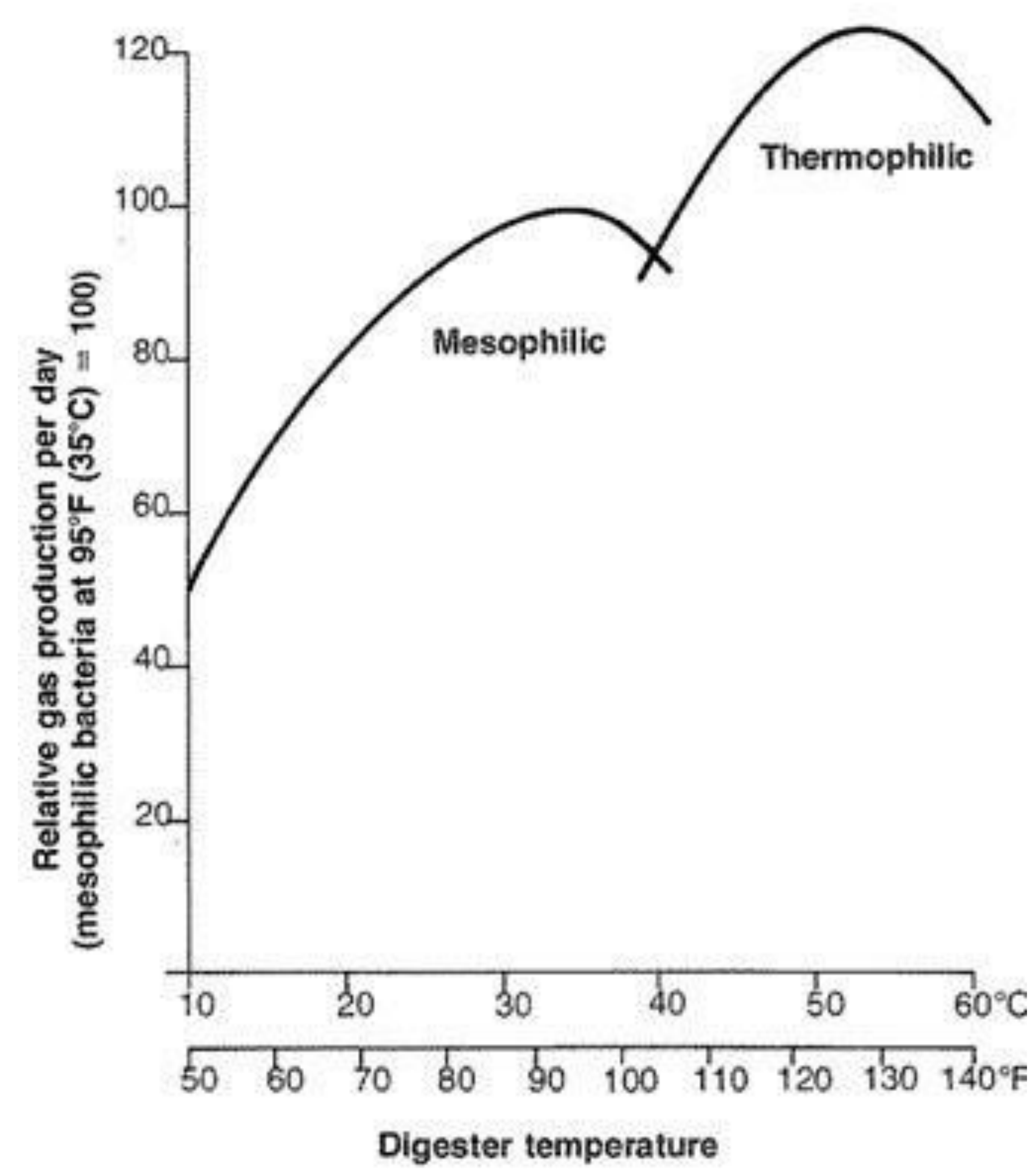

Figure 4: Comparison of Mesophilic and Thermophilic Bacteria's Optimal Temperature vs. Gas Production

Research Program

As global populations steadily rise the need for food increases as well, this puts pressure on farms not only to produce more, but to be more efficient. Between the countless crops that fail to make it to the market each season and the waste produced by them, it can be expensive to manage. However, anaerobic digestion addresses these issues by using the natural farm waste to produce energy to recoup losses while providing digestate, a nutrient rich substance that can be used as fertilizer. This symbiotic relationship between the requirements and by-products of these two processes indicates the possibility of a self-sustaining farm.

Hypothesis: Can the combination of a farm and biodigester be optimized such that all waste is eliminated?

Procedure:

- Identify the total organic waste produced by a farm containing crops and livestock.
- Determine the energy produced from that specific agricultural waste.
- Quantify the amount of energy the farm needs to operate.

Analysis:

- Compare the energy requirements of the farm to the energy produced by the digester.
- Investigate the requirements of a digestor to produce that much energy.
- Find the payback period for the initial investment of the digester versus the energy savings.

Objectives:

- Eliminate organic waste by utilizing by-products.
- Reduce energy costs and implement a renewable energy system.

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