Design of Anaerobic Digestion Facilities for Recovering Biogas from Food Wastes

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Anaerobic Digestion

- Introduction
- Principles
- Process rate limitation factors
- Parameters
- Operational considerations
- AD Systems
- Conclusions
Introduction

• Some mixed solid waste AD systems were built during the 1970s and 1980s in the US
• Substantial operating problems and high costs resulted in plant closures
• In the US, AD generally competes with landfill disposal and composting, which tend to be less costly on a unit cost basis
Introduction (cont.)

- Thousands of AD plants have been built in Europe during the last few years
- Germany and Austria built some of the first full-scale facilities in the 1980s
- The technology has now been applied in several other countries (i.e., Korea, Spain)
- Overall installed capacity of AD facilities treating the organic fraction of MSW in Europe is about 4 million tons per year
Relevant Financial Incentives

- Award “Green Certificates” (CG):
  - European Directive 2001/77/CE
  - promotes production of energy from renewable sources
  - provides financial incentive to producer (time period and amount vary from country to country)
  - one GC = 50 MWh of energy
  - in Italy, financial incentive is 0.115 €/kWhe per year (~0.138 US$/kWhe year)
  - in Italy, incentive is valid for 8 years from startup of plant – can be extended 4 more years (financial incentive reduced to 60%)
  - in Germany, incentives last over 20 years
Principles

- **DIGESTER**
- **Organic Waste**
- **Biogas**
  - Green Energy
- **Soil Conditioner**

1 m³ of Biogas at 60% CH₄
- 6 kWh
- 600 kg CO₂ emissions savings
Two-stage representation

ORGANIC MATTER

Hydrolysis/Fermentation

VOLATILE FATTY ACIDS

Gasification

BIOGAS
Design Awareness

- Pre-processing of wastes is required to produce:
  - an acceptable particle size distribution for downstream equipment (AD feeding system, etc.)
  - a “clean” feedstock (i.e., acceptable level of contamination)
- AD produces a biologically unstable process residue unless otherwise treated
Design for Hostile Feedstocks

Need proper sizing and segregation of feedstock.

Valve jammed with fiber and plastic.

Must invoke judicious selection of equipment for processing and transporting slurry.
Stability & Sustainability

• Overall, AD process rests upon maintenance of a relatively critical balance
• Initially pH declines, then gradually rises – eventually, gas is produced
• End products: methane, carbon dioxide, other gases, and relatively stable residue
Process Rate Limitation Factors

• Availability of nutrients in waste
• Cellulose converted into soluble carbohydrates
• Acid formers convert carbohydrates to low-weight fatty acids
• The final stage (methane formation) is the slowest, and thus the rate-limiting one
Physical Properties

• Particle size
• Moisture content
• Chemical composition: C/N
• Performance factors:
  - transfer of metabolic products
  - elements or compounds
Parameters

• Gas production and composition:
  - varies, depending upon substrate from 0.2 to 0.8 m³/kg of dry solids
  - composition is about 50% methane

• Destruction of volatile matter:
  - varies from 30% to 80%

• pH:
  - generally within narrow range: 6.5 to 7.5
Operational Considerations

- Mixing and formation of scum
- Loading: measured in kg of VS/m³-day
- Detention time: from 15 to 30 days, has impact on volume of reactor
- Starting a digester: culture
Digester Construction Design Principles

- Conventional
- High-rate
- Contact (fixed-bed)
Conventional

- Low solids concentration
- Dimensions depend upon total amount of waste that must be treated
- Gas production impacted by many factors
Conventional Digestion (low solids)

- Raw Sludge
- Gas
- Scum
- Supernatant
- Actively Digesting Sludge
- Stabilized Sludge
- Digester Gas
- Supernatant
- Digested Sludge

Diagram: Flowchart showing the process of conventional digestion with stages labeled as Raw Sludge, Gas, Scum, Supernatant, Actively Digesting Sludge, Stabilized Sludge, and Digested Sludge.
High Rate

- Best suited for large-scale operations
- Two-stage operation in series (each stage takes place in a different digester)
- First stage is active: thoroughly agitated, short detention time
- Second stage: material is not mixed, serves as a settling chamber
High-Rate Digestion (low solids)
Contact

- Popular version is the fixed-bed
- Provide a surface upon which organisms attach and form a film
- Film is bathed by the waste
- Film falls off periodically
Modern Technologies

- Essentially divided as a function of total solids content in the reactor:
  - dry digestion: TS > 15%
  - wet digestion: TS < 12%
Digester Heating

Several alternatives:
- indirectly or directly
- solar, fossil fuel, biogas
Example of an installation for the treatment of organic matter
Areas for pre-treatment and segregation
Wet Digestion

The electrical energy produced is used within the facility.
Metallic Digester

Digester made of steel. The main structure is made of galvanized steel, with adhesive stainless steel film inside. Photos on right shows the insulation; sheet metal (green) that protects the insulation; and the pipes for heating the digester.
Where possible, digesters are built below ground in order to achieve low heat losses. Solids are loaded by means of a hopper with a screw feed.
Lobe type pump equipped with shredding unit. This is particularly useful in avoiding clogging in co-digestion.
Method for Loading the Digester

Biomass is loaded into a hopper equipped with screws (Liquitech).
Types of Reactor Mixers

Horizontal shaft with paddles (left, Hockreiter) propeller type with inclined shaft (right, Envicom).
Dry Anaerobic Digestion
Dry Anaerobic Digestion
Dry Anaerobic Digestion
Co-generation Equipment
Range of Methane Production Obtained at Existing Facilities

Dry: $T = 20 \text{ [d]}$; $10 \text{ [kg/m}^3\text{d]} : V_{\text{biogas}} = 3 \text{ m}^3/\text{m}^3\text{d} : V_{\text{biogas}} = 300 \text{ m}^3/\text{MgDom}$ $T = 10 \text{ [d]}$; $18 \text{ [kg/m}^3\text{d]} : V_{\text{biogas}} = 3 \text{ m}^3/\text{m}^3\text{d} : V_{\text{biogas}} = 167 \text{ m}^3/\text{MgDom}$

Wet: $T = 20 \text{ [d]}$; $2.5 \text{ [kg/m}^3\text{d]} : V_{\text{biogas}} = 1 \text{ m}^3/\text{m}^3\text{d} : V_{\text{biogas}} = 400 \text{ m}^3/\text{MgDom}$ $T = 10 \text{ [d]}$; $5 \text{ [kg/m}^3\text{d]} : V_{\text{biogas}} = 1.6 \text{ m}^3/\text{m}^3\text{d} : V_{\text{biogas}} = 320 \text{ m}^3/\text{MgDom}$

Source: University of Duisburg-Essen, Germany
Research in Pre-Processing of Organics

Research Comminutor and Monitoring Equipment

Close-up View of Cutters
Lab-Scale Organic Fraction of MSW/Sludge Digesters in Richmond, California (1973)
Pilot Food Waste Digester in Richmond, California (1984)
Conclusions

• Define quantities and characteristics of the feedstock
• Establish acceptable specifications for the biogas and process residue
• The implementation of separate collection of food waste simplifies the design of facilities considerably--otherwise, careful pre-processing is needed
Conclusions

• Developing financially sustainable AD systems in the US currently is a challenge given the alternatives

• Conditions in Europe favor development and implementation of AD systems