Module 4:
AD Design & Technology

4.1: Introduction

4.2: Passive AD systems

4.3: Low-rate AD systems

4.4: High-rate AD systems

4.5: Dry AD systems

4.6: Choosing an AD design

4.7: 'Extras'

This curriculum is adapted from: eXtension Course 3: AD, University of Wisconsin

Module 4:
AD Design & Technology

4.1: Introduction

4.2: Passive AD systems

4.3: Low-rate AD systems

4.4: High-rate AD systems

4.5: Dry AD systems

4.6: Choosing an AD design

4.7: 'Extras'

This curriculum is adapted from: eXtension Course 3: AD, University of Wisconsin

Introduction

AD designs differ…

… but all designs perform the **same basic function**:

- Contain organic matter;
- In the absence of oxygen; and
- Maintain operating temperatures.

Four broad AD categories:

1. Passive AD
2. Low-rate AD
3. High-rate AD
4. Dry AD

Assessment!

Please answer the questions in **section 4.1** of the Module 4 Assessment.

Module 4:
AD Design & Technology

4.1: Introduction

4.2: Passive AD systems

4.3: Low-rate AD systems

4.4: High-rate AD systems

4.5: Dry AD systems

4.6: Choosing an AD design

4.7: 'Extras'

This curriculum is adapted from: eXtension Course 3: AD, University of Wisconsin

Passive Systems

Covered lagoon

1. Manure is placed in a **pit** covered with an impermeable & **gas-tight cover**.
2. **Oxygen is depleted** and anaerobes produce biogas.
3. **Biogas** accumulates under the cover and is piped to a genset.
4. As manure is pumped into the covered lagoon, digester **effluent** flows to a smaller open storage pit.

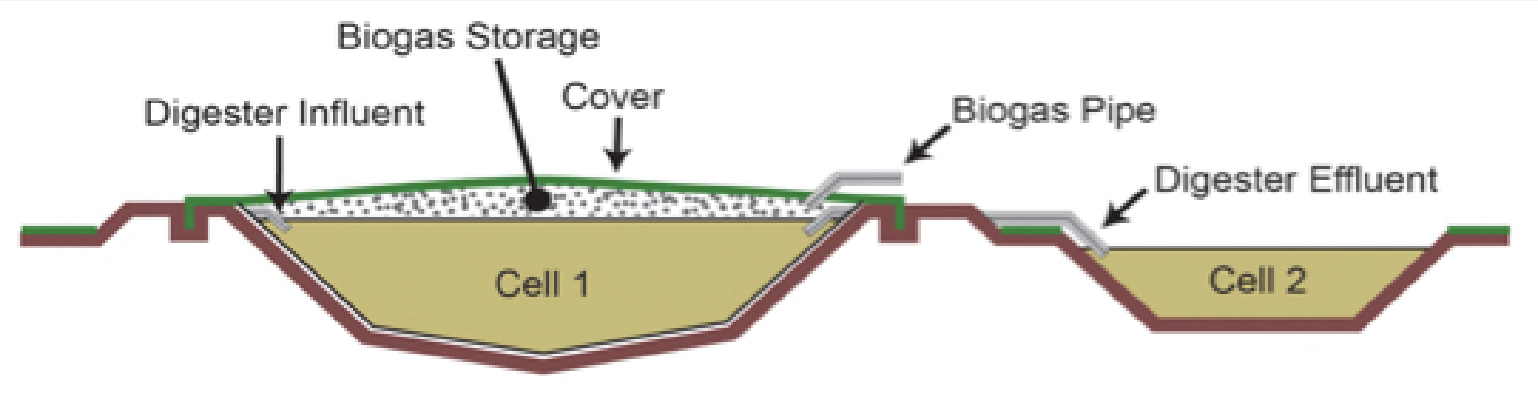
Covered lagoon

Advantages:

- Inexpensive
- Works with hydraulic flushing
- Simple operation

Disadvantages:

- Poor mixing
- Poor energy yield (inefficient)
- 30 – 60 day HRT
- Settled solids reduce useable volume
- Limited AD season in cold climates. Biogas production stops <68°F or 20°C



Assessment!

Please answer the questions in **section 4.2** of the Module 4 Assessment.

Module 4:
AD Design & Technology

4.1: Introduction

4.2: Passive AD systems

4.3: Low-rate AD systems

4.4: High-rate AD systems

4.5: Dry AD systems

4.6: Choosing an AD design

4.7: 'Extras'

This curriculum is adapted from: eXtension Course 3: AD, University of Wisconsin

Low-rate AD systems

Low-rate AD

Low-rate AD: an AD system where feedstock remains in the system for long periods of time to maximize biogas production.

- **Long HRT**

Types:

1. Complete-mix AD
2. Plug-flow AD

Complete-mix AD

Complete-mix AD: one or more tanks in which manure is heated and mixed.

1. Feedstock is pumped in **daily**.
2. Input **displaces** an equal volume of effluent (and bacteria) from the tanks.
3. Slurry is **stirred** continuously or intermittently.
4. HRT is generally **20 – 30 days**.
5. Generally **low solids content** of 3 – 6 % solids in the slurry.
   Note that tanks size must increase as solids decrease.

One phase vs. two-phase:

- One-phase systems: a single tank.
- Two phase systems: two linked tanks.
  - First: fermentation of feedstock to organic acids
  - Second: production of methane from organic acids

Complete-mix AD

Advantages:

- Efficient
- Can handle different levels of dry matter
- Can handle energy crops
- Good mixing
- Good solids destruction

Disadvantages:

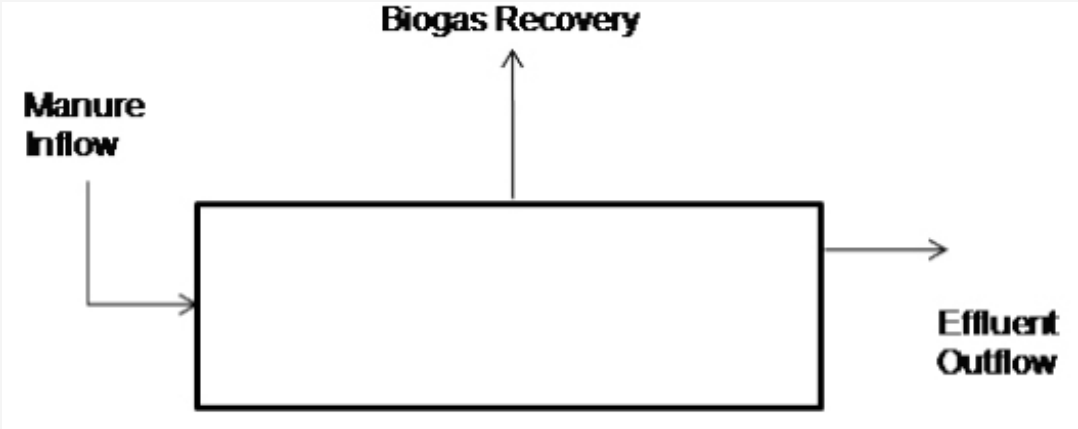
- Difficult to control how much time material spends in the AD
- Bacteria wash out
- Relatively expensive

Plug-flow AD

Plug-flow AD: one long underground tank in which manure is heated

- Plug-flow tanks are generally five-times longer than wide.
- Can be "C" or "U" shaped.

1. A **'plug'** of manure (10 – 20% total solids) is pumped in **daily**. Some operators add solids to thicken manure.
2. Input **displaces** the most distant and digested plug from the other end of the tank.
3. **Little** or no mixing occurs, but the high solids content keeps particles from settling.
4. HRT generally **15 – 20 days**.



Plug-flow AD

Advantages:

- Inexpensive
- Simple to repair and operate
- Can be adapted to accept energy crops

Disadvantages

- Poor mixing
- Poor energy yield
- Hard to remove settled solids
- Membrane top may be affected by wind and snow

Assessment!

Please answer the questions in **section 4.3** of the Module 4 Assessment.

Module 4:
AD Design & Technology

4.1: Introduction

4.2: Passive AD systems

4.3: Low-rate AD systems

4.4: High-rate AD systems

4.5: Dry AD systems

4.6: Choosing an AD design

4.7: 'Extras'

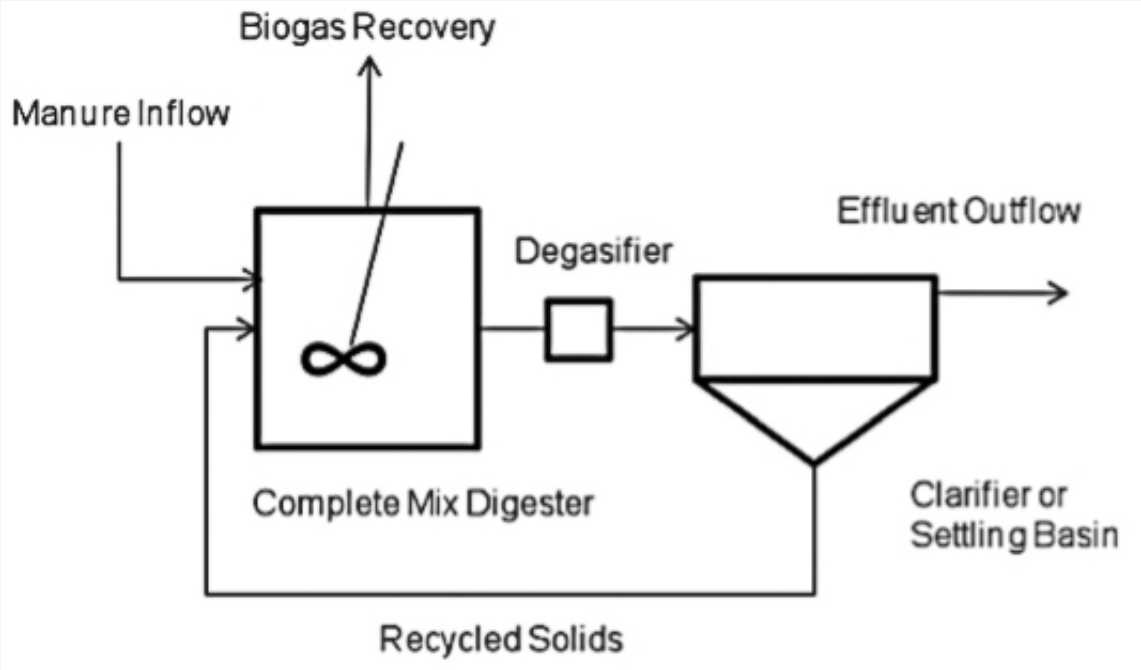
This curriculum is adapted from: eXtension Course 3: AD, University of Wisconsin

High-rate AD systems

Low-rate AD with solids recycling

Solids recycling modifies the complete-mix and plug-flow designs described by **returning some settled, high-solids effluent to the feedstock inlet**.
This returns some microbes that would have been washed out, increased AD efficiency.

- Advanced plug-flow
- Contact stabilization digesters or anaerobic contact digesters



Low-rate AD with solids recycling

Advantages:

- More efficient
- Useful microbes get a second chance
- Smaller vessel size

Disadvantages:

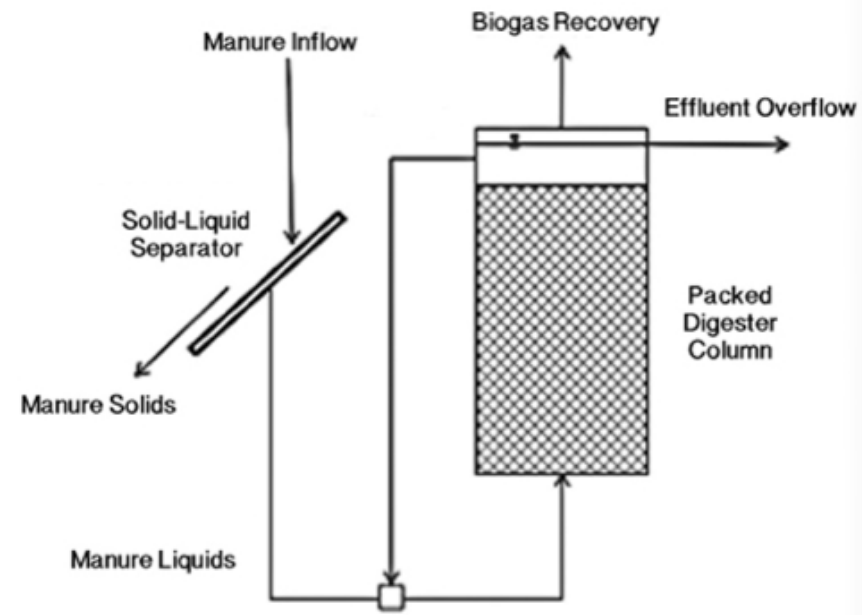
- Increased operational complexity
- More mechanical components

Fixed-film AD

Fixed-film AD: a column packed with media (wood chips or small plastic rings) on which AD microbes are grown and remain as a biofilm.

- aka attached growth AD or anaerobic filters

1. Dilute manure or liquid feedstock (**1 – 5% total solids**) is pumped up and through the media. Solids must be filtered out prior to feeding.
2. Effluent is constantly **pushed out** of the top.
3. Effluent is usually **recycled** to maintain a constant upward flow.
4. HRT is **5 days or less**, so tank sizes can be small.



Fixed-film AD

Advantages:

- Efficient
- Low bacterial wash out
- High gas production for a small AD tank size

Disadvantages:

- Expensive
- Suspended solids must be filtered out before AD. This increases complexity & may lower biogas yield.
- Bacterial growth media may plug, blocking AD flow.

Suspended-media AD

Suspended-media AD: AD microbes are suspended in a constant upflow of liquid. Small particles wash out while larger particles remain and develop a biofilm of AD microbes. Effluent is often recycled to maintain upward flow.

<u>aka</u>

- Fluidized bed AD
- Upflow anaerobic sludge blanket (UASB) → <3% total solids
- Induced blanket reactor (IBR) → 6 – 12% total solids

1. Dilute manure or liquid feedstock (**1 – 5% total solids**) is pumped upward.
2. Effluent with small particles is **constantly pushed out** of the top.
3. Large particles (with AD microbe biofilm) are **retained** in the column.
4. Effluent is usually **recycled** to maintain a constant upward flow.

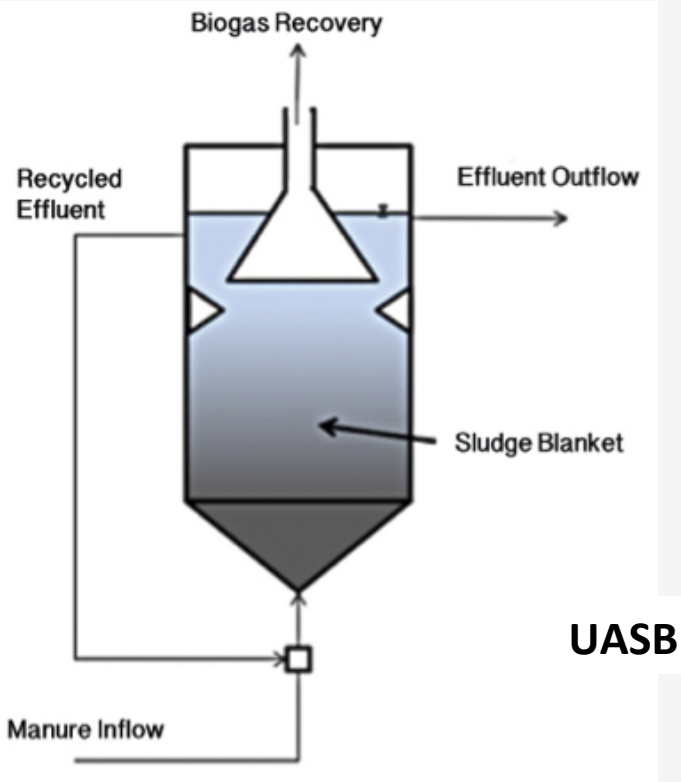
Suspended-media AD

Advantages:

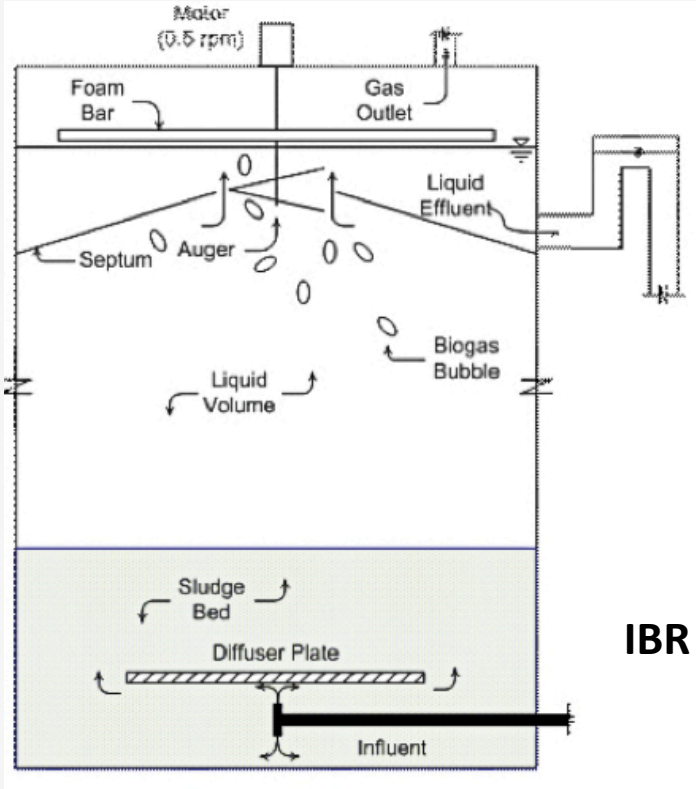
- Very efficient
- Can treat high-strength wastewater
- Good bacterial retention

Disadvantages:

- Expensive
- Complex operation
- Cannot handle FOG



UASB



IBR

Sequencing batch AD

Sequencing batch AD (ASBR): in this variant of an intermittently mixed AD a tank is operated in four distinct phases.

1. The tank is **filled** with manure or feedstock.
2. Feedstock is **mixed** during the reaction phase.
3. Stirring is stopped and solids are **settled** during the settle phase.
4. Liquid effluent is drawn off during the **decant** phase.

This operation cycle may be repeated up to four times per day and biogas is removed as it is made.

- Liquid HRT can be **as short as 5 days**.
- Work will with a variety of feedstock concentrations, down to completely soluble.
- **Sludge is removed periodically** and has a high concentration of nutrients.

Sequencing batch AD

Advantages:

- High gas yield per substrate load
- Works well with dilute manure
- Small reactor size
- Can accept high energy liquid co-substrates

Disadvantages:

- Relatively expensive
- Complex operation
- Low gas yield per reactor volume
- Works best with dilute (low solids) substrates

Assessment!

Please answer the questions in **section 4.4** of the Module 4 Assessment.

Module 4:
AD Design & Technology

4.1: Introduction

4.2: Passive AD systems

4.3: Low-rate AD systems

4.4: High-rate AD systems

4.5: Dry AD systems

4.6: Choosing an AD design

4.7: 'Extras'

This curriculum is adapted from: eXtension Course 3: AD, University of Wisconsin

Dry AD systems

Dry (high-solids) AD

Dry AD (HSAD): solid, stackable organic feedstock is stacked in airtight bays.

- Each bay operates as a batch AD.
- **(**aka dry fermentation)

1. High-solids feedstock (**25 – 50% solids**) is stacked in airtight bays.
   Feedstock may include manure but the pile must have 'air' gaps throughout.
2. **Leachate** (liquids) are collected as they drain from the pile…
3. … and **recirculated** by spraying back onto the top of the pile.
4. A **biofilm** of bacteria develops on the pile & soluble organic acids pass over the biofilm again and again until digestion is complete.

Dry (high-solids) AD

Advantages:

- Uses solid feedstock
- Has a long aerobic phase as all of the air in the chamber is consumed prior to the start of the anaerobic phase

Disadvantages:

- Requires at least 25% solids and stackable feedstock
- Complicated operations
- Expensive

Assessment!

Please answer the questions in **section 4.5** of the Module 4 Assessment.

Module 4:
AD Design & Technology

4.1: Introduction

4.2: Passive AD systems

4.3: Low-rate AD systems

4.4: High-rate AD systems

4.5: Dry AD systems

4.6: Choosing an AD design

4.7: 'Extras'

This curriculum is adapted from: eXtension Course 3: AD, University of Wisconsin

Choosing an AD design

Criteria for choosing an AD system?

If the AD system is **chosen thoughtfully**, it will require only modest daily operational attention and periodic maintenance.

- Will this AD technology easily become a component of the farm's daily operations?
- Is the AD technology suited to the farm's manure handling system?
- Is the AD technology and design suited to co-substrates that may be sourced and used locally?

Steps in thinking it through?

1. Answer some questions about the **farm's management needs** and **environmental needs** that will determine whether AD is a potential benefit.
   - Meyer & Power (2011) discuss the benefits & challenges of on-farm AD & provide formulas that determine the fixed cost (in $ 2008) of lagoon, complete-mix & plug-flow digesters, based on herd size.

↓ …if yes

2. Conduct a more **in-depth feasibility study** using tools or consultants.
   - DIGESTER_ECON.XLSM spreadsheet created by William Lazarus at the University of Minnesota
   - Biogas economics spreadsheet from Brent Glory at Cornell
   - FARMWARE program available on-line from AgSTAR (*dormant?*)
   - Consultants / engineers

AD co-products can be vital to viability

AD provides farmers with many benefits, but not all of them provide **fiscal** benefits.

- Odor reduction
- Environmental benefits
- Ease of manure handling

Therefore, it's important to **make each co-product contribute** to the economic success of the project:

- Maximize electric income (net-metering vs. direct sale & purchase)
- Recover waste AD heat to offset fuel use or sell it
- Tipping fees for accepting off-farm feedstock?
- Sale of separated solids for bedding or compost base

Regulations factor into AD decisions

AD technology itself is not subject to federal regulations.
Instead, AD regulation is happening on a **state-by-state basis** and is not consistent across the US.

However, handling of waste streams and the impact of wastes and nutrients on land and waterways is regulated at **multiple levels**: local, state and federal.

Which agencies regulate AD? Often agencies that regulate:

- Solid waste
- Wastewater
- Agriculture

Assessment!

Please answer the questions in **section 4.6** of the Module 4 Assessment.

Module 4:
AD Design & Technology

4.1: Introduction

4.2: Passive AD systems

4.3: Low-rate AD systems

4.4: High-rate AD systems

4.5: Dry AD systems

4.6: Choosing an AD design

4.7: 'Extras'

This curriculum is adapted from: eXtension Course 3: AD, University of Wisconsin

Extras

What's an extra?

We're defining **"extras"** as equipment not strictly necessary for the anaerobic digestion process, but that add co-product value or help meet regulatory requirements.

- Pasteurizing units ← Feedstock module
- Biogas scrubbing equipment
- Biogas compression equipment ← Power generation module
- Heat recovery equipment
- Solids separation from effluent ← Nutrient management module
- Nutrient separation equipment

Links are provided with this module, but **details** will be discussed in other modules.

- An integrated biorefinery approach that emphasizes co-products is discussed in the last module, on the future of AD.

Assessment!

Please answer the questions in **section 4.7** of the Module 4 Assessment.