Biomass: Basics, Bio-conversion, crop and sewage treatment

- Introduction
- Basics
- Multifunction of biogas
- Scheme of a biogas plant
- Types of digestion
- Operation, control & costs of plant
- Application of biogas
- Principle of the fermentation
- Impact parameters
- Literature

Dr. Spiros Alexopoulos
Summer School in RES, Patra 4.07.2012
Biomass feed stocks

Wood Residues
- Sawdust
- Wood chips
- Wood waste pallets
- Crate discards
- Wood yard trimmings

Agricultural Residues
- Corn stover
- Rice hulls
- Sugarcane bagasse
- Animal waste

Energy Crops
- Hybrid poplar
- Switchgrass
- Willow

Fuel Heating value
- biogas 6.0 kWh/m³
- wood 4.4 kWh/kg
- crop 4.2 kWh/kg

Fuel Heating value
- gas 8.3 kWh/m³
- oil 11.7 kWh/kg
- lignite 5.6 kWh/kg
Biomass transformation as energy

**Direct Combustion**

- Heat, Power Generation
  - (Fuel) Gas
  - Synthetic Gas
  - Liquid Fuel

**Thermo chemical Transformation**

- Gasification
- Thermal Cracking
- Direct Liquefaction
- Low Temperature Gasification
- Hydrogen, Methane

**Biochemical Transformation**

- Anaerobic Digestion
  - Methane
- Aerobic Pyrolysis
  - (Compost)
  - Ethanol
- Fermentation

**Others**

- RDF, Carbonization, Bio-Diesel

Introduction
Development of biogas plants

Introduction
Biogas industry in Germany

Introduction
Facts

- Total energy potential of Germany: 752 PJ
- Power production in 2005: 3.2 Mio. kWh
  650 MW\textsubscript{el} plants installed in Germany
- 2.5 Mio. tons CO\textsubscript{2} per year avoided
  resulting in 2020: 60 Mio. tons CO\textsubscript{2}
- World estimation for 2020: 15,000 MW
  Germany: 9,500 MW, 20 % electricity production
- Extra price for consumer max. 0.1 Cent/kWh
  Buyback price for a new plant: 15.5 Cent/kWh
Biomass potential of Greece

- Installed biogas plants (2008): 24 MW
- Planned biogas plants: 32 MW
- Estimation for 2010: 60 MW

Geographical Distribution of Agricultural Residues in Greece (2000)

Source: CRES 2003

Geographical Distribution of Animal Wastes in Greece (2000)
### Examples of biogas plants in Greece

<table>
<thead>
<tr>
<th>Company</th>
<th>Activity</th>
<th>Electrical Installed Capacity (MW&lt;sub&gt;e&lt;/sub&gt;)</th>
<th>Thermal Installed Capacity (MW&lt;sub&gt;e&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Entity Psytalia</td>
<td>Sewage treatment plant</td>
<td>7.37</td>
<td>2.7</td>
</tr>
<tr>
<td>Consortium (munic.+private) Liosia</td>
<td>Landfill gas</td>
<td>13.00</td>
<td>16.55</td>
</tr>
<tr>
<td>Munic. Ent. Volos</td>
<td>Sewage treatment plant</td>
<td>0.35</td>
<td>0.5</td>
</tr>
<tr>
<td>Munic. Ent. Heraklio</td>
<td>Sewage treatment plant</td>
<td>0.19</td>
<td>0.25</td>
</tr>
<tr>
<td>Munic. Ent. Chania</td>
<td>Sewage treatment plant</td>
<td>0.17</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>Electrical Installed Capacity MW&lt;sub&gt;e&lt;/sub&gt;</th>
<th>Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tebloni, Corfu</td>
<td>4</td>
<td>Landfill gas</td>
</tr>
<tr>
<td>Thermi, Thessaloniki</td>
<td>8</td>
<td>Landfill gas</td>
</tr>
<tr>
<td>Liosia, Attiki</td>
<td>9.5</td>
<td>Landfill gas</td>
</tr>
<tr>
<td>Metamorfosi, Attiki</td>
<td>0.665</td>
<td>Sewage treatment biogas</td>
</tr>
<tr>
<td>Patra, Achaia</td>
<td>0.9</td>
<td>Sewage treatment biogas</td>
</tr>
<tr>
<td>Fillipiada, Preveza</td>
<td>4.09</td>
<td>Pig manure</td>
</tr>
</tbody>
</table>

Introduction
## Composition of biogas

<table>
<thead>
<tr>
<th>Component</th>
<th>Symbol</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>50 - 75 Vol.-%</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>25 - 45 Vol.-%</td>
</tr>
<tr>
<td>Water vapor</td>
<td>H₂O</td>
<td>2 - 7 Vol.-%</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O₂</td>
<td>&lt; 2 Vol.-%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N₂</td>
<td>&lt; 2 Vol.-%</td>
</tr>
<tr>
<td>Ammonia</td>
<td>NH₃</td>
<td>&lt; 1 Vol.-%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H₂</td>
<td>&lt; 1 Vol.-%</td>
</tr>
<tr>
<td>Sulfide</td>
<td>H₂S</td>
<td>20 – 20,000 ppm</td>
</tr>
</tbody>
</table>

[ppm: Parts per Million]

Source: www.nachwachsende-rohstoffe.de

Basics
Importance of burning biogas

Bacteria digest organic compounds in oxygen free environments

Anaerobic digestion is a naturally occurring process

Methane 21x worse than CO₂ in causing global warming

Removing 1 ton methane from atmosphere = getting rid of 21 tons CO₂

Burning methane converts the methane to CO₂

CO₂ equivalent for methane is 1

Burning methane does not increase carbon in the carbon cycle.
Definition of cattle unit (GVE)

1 GVE produces 1.5 m³ biogas/day

One cattle unit (GVE) equals:

– one cow
– five calves
– six porks
– 250 chicken
Slower carbon cycle can increase atmospheric carbon for 20 to 50 years – Burning forest biomass is a slow cycle
**CO₂ contemporary cycle**

**Contemporary Carbon Cycle**

**Atmosphere**

**CO₂**

**CH₄ + 2O₂ → CO₂ + 2H₂O**

**Methane**

**Burned**

**Carbon sources**

Food wastes from meat or plant sources, decaying of organic material

**Animal and plant respiration produces CO₂**

**Through Photosynthesis**

Plants use CO₂ to make carbon compounds

**Forest Fires**

Burning of biomass

**Plants consumed as food**

**Much of the carbon consumed ends up in manure**

**Much of the carbon consumed ends up in manure**

**Basic concepts**

- CO₂ is a greenhouse gas.
- Plants absorb CO₂ through photosynthesis.
- Methane (CH₄) is produced by the burning of biomass.
- Animal and plant respiration also produce CO₂.
- Food wastes from meat or plants, decaying organic material, contribute to CO₂ emissions.

**CO₂**

**Contemporary Carbon Cycle**
A need for speed

A fast carbon cycle is important in order to prevent even temporary increase in CO₂

CO₂

In Atmosphere

Methane
Burned as fuel

Crops grown and harvested over several months
Carbon continually recycled

Grain, grass, food

Plants consumed as food

Food Waste

Manure

Digester
CO$_2$ and cycle of matter

CO$_2$ Cycle

- Fertilizer
- Heat
- Electricity
Cycle of matter

Sunlight

Photosynthesis

Necrosis

Manuring

Manure

Organic matter

Fermentation

Biogas

Electricity + Heat
Multifunction of biogas

- Power, heat & fuel
- Reduces pathogens
- Weed seed reduction
- Fly control
- Avoidance of methane
- Protects water resources
- Feeding gas into the distribution net
- Reduces odor from land application
- Strong industrial growth
- Saving of mineral manure

Multifunction of biogas
Biogas process

**INPUT**
- URBAN
- AGRICULTURE
- INDUSTRY

**PRE-TREATMENT**
- Mixing
- Macerating
- Hygienisation/ sterilisation
- +/- other pre-treatment: e.g. concentration

**DIGESTION**

**POST-TREATMENT**
- STORE
- Separate
- Upgrade

**OUTPUT**
- BIOGAS
- N - RICH FLUID
- P - RICH SOLIDS

**After-treatment**
- Land application
- Move and apply
- Transport market / or disposal

Scheme of a plant
Biogas plant design

Scheme of a plant
Scheme of a continuous biogas plant

Manure + biomass

Stirring device
mechanic or hydraulic

Condensate
separator

Filter

Gas pipe

Condensate
separator

Heating system

Digester
35 or 55 °C

Tank

Pump

Heating

Insulation

Manure end product

Storage
60-70% CH₄
30-35% CO₂
0 - 1% H₂S
0 - 1% H₂
0 - 1% O₂
0 - 3% N

Heating
Warm water
Drying
Electricity
Lightning
Transport

Scheme of a plant
Biomass energy in developing countries

Crop residue

Biogas from pig waste

Scheme of a plant
Dom biogas plant for developing countries

Scheme of a plant

Gas pipe
Clearance

Fermenter
(Dom)

Substrate

Digester

Scheme of a plant
Scheme of a plant:

- Graduated cylinder
- Fermenter
- Stirrer
- Gas storage
- Flask
- Burner
- Heating
Fermenter types

Complete stirring reactors

Advantages:
- cost-efficiency above 300 m³
- Variable operation
- Easy maintenance

Disadvantages:
- Huge plants need to be covered
- Bypass flow possible
- Swimming and sinking layers possible

Source: Weiland, FAL 2006
Fermenter types

Plug flow reactors

**Advantages:**
- Pumpable substrates
- Compact system
- Separation of digestion layers in the flow
- Avoidance of swimming and sinking layers
- Avoidance of bypass flow
- Small residence time
- Small heat losses

**Disadvantages:**
- Cost-effective only in small dimension
- Total emptying of the device needed

Source: Weiland, FAL 2006

Types of digestion
- Gas-proof cover with up to 34 m fermenter diameter
- Central stirring device not applicable

- Foil cover used by 50% of standing fermenters
- double foil used by 60% 
- easy foil used by 40%

Source: Weiland, FAL 2006
Huge fermenter with central stirring

- Odor emission possible
- Use in huge fermenters (up to app. 4000 m³)

Source: Weiland, FAL 2006
## Characteristics of the fermenter types

<table>
<thead>
<tr>
<th></th>
<th>Covered Lagoon</th>
<th>Complete Mix</th>
<th>Plug Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level of Technology</strong></td>
<td>Low</td>
<td>Medium/High</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Digestion Vessel</strong></td>
<td>Deep lagoon</td>
<td>Round, square in/above ground</td>
<td>Rectangular in ground</td>
</tr>
<tr>
<td><strong>Supplemental Heat</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Solids Concentration</strong></td>
<td>0.5-2%</td>
<td>3-8%</td>
<td>6-11%</td>
</tr>
<tr>
<td><strong>HRT (days)</strong></td>
<td>45+</td>
<td>15+</td>
<td>15+</td>
</tr>
<tr>
<td><strong>Optimum Location</strong></td>
<td>Warm climates</td>
<td>All climates</td>
<td>All climates</td>
</tr>
</tbody>
</table>

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Relative frequency of fermenter types

- Submerged stirring: 60%
- Central stirring: 10%
- Form stirring: 20%
- Gas pressing: 5%
- n.n.: 5%

Types of digestion

Biogas plants after 2004

Source: Weiland, FAL 2006
Ways of charging: Two different processes

**Batch process**

- charging and discharging phases
- defined residence time
- no constant gas production

**Interchangeable tank**

- 2 tanks
- defined residence time
- uniform gas production
- Important for dry fermentation

**Phase 1: discharging**

Storage tank full → Fermenter empty → Storage tank full

**Phase 1: fermentation**

Slurry store → charging tank 1 → fermentation tank 2 → discharging storage tank

**Phase 2: emptying tank 2**

Slurry store → fermentation tank 1 → discharging → charging tank 2 → storage tank

**Phase 3: fermentation**

Slurry store → fermentation tank 1 → charging tank 2 → discharging storage tank

**Phase 4: emptying tank 1**

Slurry store → discharging tank 1 → fermentation tank 2 → charging storage tank

Operation
Continuous ways of charging

**Flow-through Process**
- one up to multiple daily charging
- Fermenter always filled
- uniform gas production
- Good load of the digester
- Danger of bypass

**Combined Process**
- Fermenter and storage tank covered
- Uniform gas production
- no defined residence time
- possibility of bypass

**Storage Process**
- Fermenter & storage tank combined and covered
- Complete discharging
- Slowly advancing continuous charging
- Less uniform gas production
- Longer residence time

---

Slurry store
Fermenter
Storage tank

Slurry store
Fermenter
Storage tank

Slurry store
Plant empty
Plant full
Dry fermentation

Biogas production

Fermenter 1
Fermenter 2
Fermenter 3
Fermenter 4

Time

Operation
Dry fermentation

Substrate → Fermenter

Mixer

Manure remainder → Solid separation → Process water

→ high capacity (> 20,000 t/a)

Biogas

Operation

Solid
Components of a biogas plant

Storage of 5000 t corn silage

Station for corn silage charging twice a day

Tank mixer for the homogenization of corn silage and manure

Continuous corn feeding in premixed tank (20 t/day)

Heat exchanger

Operation
Gas processing

**Problem:** Biogas is steam saturated and contains beside of CH$_4$ and CO$_2$ also small amounts of H$_2$S

$\rightarrow$ H$_2$SO$_4$ corrodes components!

---

**Desulphurization:**

**biological:**

$\text{H}_2\text{S} + \text{O}_2 + \text{Bacteria} \rightarrow \text{S}$

**chemical:**

$\text{H}_2\text{S} + \text{chemical additives} \rightarrow \text{Sulfides,..}$

Additives: e.g. caustic soda, iron chlorate

---

**desulphurization und drying of the biogas!**

---

Operation
### Example

<table>
<thead>
<tr>
<th>Capacity:</th>
<th>32,000-35,000 tons &amp; fermenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric capacity:</td>
<td>1000 m³</td>
</tr>
<tr>
<td>Biogas production:</td>
<td>485 Nm³/h</td>
</tr>
<tr>
<td>Treatment capacity per year:</td>
<td>approx. 3,9 Mio. Nm³ biogas</td>
</tr>
<tr>
<td>capacity per year:</td>
<td>approx. 40.000.000 kWh into gas net</td>
</tr>
<tr>
<td>Supply:</td>
<td>Gas net of Munich</td>
</tr>
<tr>
<td>Investment:</td>
<td>approx. 9,800,000 Euro</td>
</tr>
<tr>
<td>Start of Construction:</td>
<td>June 2006</td>
</tr>
<tr>
<td>Starting up:</td>
<td>December 2006</td>
</tr>
</tbody>
</table>

Source: www.biogas-netzeinspeisung.at/anlagenbeispiele
Solid biomass charging

Professional solids charging for daily rations from 10 - 50 tons/day

Operation
PC control of a biogas plant

- **Effective power**: 165 kW
- **Pressure**: 0.9 mbar
- **Gas amount**: 15996 qm
- **CH4 (Vol%)**: 50.56
- **H2S (ppm)**: 226
- **O2 (Vol%)**: 0.30
## Example

<table>
<thead>
<tr>
<th>Construction</th>
<th>Dimension of Fermenter</th>
<th>460 m³</th>
<th>98,000 €</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor</td>
<td>Residence time</td>
<td>50 d</td>
<td>3,000 €</td>
</tr>
</tbody>
</table>

**Total Investment**: 101,000 €

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amortisation</td>
<td>7,500 €</td>
<td>€/y</td>
</tr>
<tr>
<td>Interest</td>
<td>3,000 €</td>
<td>€/y</td>
</tr>
<tr>
<td>Insurance</td>
<td>500 €</td>
<td>€/y</td>
</tr>
<tr>
<td>Maintainance</td>
<td>3,000 €</td>
<td>€/y</td>
</tr>
<tr>
<td>Costs of labour</td>
<td>4,000 €</td>
<td>€/y</td>
</tr>
<tr>
<td>Electricity &amp; ignition</td>
<td>2,500 €</td>
<td>€/y</td>
</tr>
</tbody>
</table>

**Costs of operation**: 20,500 €/y

<table>
<thead>
<tr>
<th>Utilizable energy production</th>
<th>122,000 kWh/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remuneration standard</td>
<td>11.5 cent/kWh</td>
</tr>
<tr>
<td>Remuneration bonus</td>
<td>6 cent/kWh</td>
</tr>
<tr>
<td>Remuneration CHP</td>
<td>2 cent/kWh</td>
</tr>
</tbody>
</table>

**Gains**: 22,000 €/y

**Earnings**: 1,500 €/y
Application of biogas

- Block heat and power block
- Micro turbines
- Fuel cells
- Gas supply net
- Fuel
- Power plants
**biogas plant**

- From 500 kg cow per day 1.5 m³ biogas
- From 1 ha grass 6,000 m³ biogas
- From 1 ha 12,000 m³ biogas
Process of fermentation

Hydrolysis

1. Protein, Carbohydrates, Fat

Decomposition of acid

2. Acetic acid, Acids, Alcohol

Methane production

3. Acetic acid

Biogas

CH\text{4}, CO\text{2}

Fermentative bacteria

1. 1

Acetogenic bacteria

2. 2

methanogenic bacteria

3. 3

Principle of the fermentation
Stage I

Hydrolysis

Polymers → Monomers

Protein → Amino acid
Protein → Fatty acids
Fat → Fatty acids
Carbohydrates → Saccharide

Intermediate products:
Acetic acid \( \text{CH}_3\text{COOH} \)
Alcohol

\[
\begin{align*}
\text{H}_2\text{O} & \quad \text{CO}_2 \\
\text{H}_2 & \quad \text{NH}_4
\end{align*}
\]

Principle of the fermentation
Stage II

Decomposition of acid

Products

H₂O
H₂
CO₂

Brew end product CH₃COOH

Principle of the fermentation
Stage III

Methane production

Acetic acid from stage I → CH$_4$ H$_2$ H$_2$S NH$_3$

Acetic acid from stage II → CH$_4$ H$_2$ H$_2$S NH$_3$

Principle of the fermentation
Ecology of the Methanogens

- Methanogens require **anaerobic conditions**
- In the digestive systems of herbivores, marshes or lake bottoms.
- Many require **warm conditions** to work best.
- They are associated with a **source of organic matter** (e.g. plant remains or sewage) and with **heterotrophic bacteria**
- The heterotrophs break down this organic matter to release compounds such as ethanoic acid (acetic acid or vinegar) and hydrogen
- The ethanoate ions are a substrate for the methanogens
Biochemistry of the methanogens

- Methanogens are **chemoautotrophs**
- Methanogens produce methane:
  - Using ethanoate (acetate) that may be derived from the decomposition of cellulose:
    \[
    \text{CH}_3\text{COO}^+ + \text{H}^- \rightarrow \text{CH}_4 + \text{CO}_2 + 36 \text{ kJ mol}^{-1}
    \]
  - Or using hydrogen and carbon dioxide produced by the decomposers:
    \[
    4 \text{H}_2 + \text{CO}_2 \rightarrow \text{CH}_4 + 2 \text{H}_2\text{O} + 130.4 \text{ kJ mol}^{-1}
    \]
Impact parameters

- Substrate form
- Concentration of organic dry matter
- pH
- Temperature
- Digestion time (residence time in the fermenter)
- Substrate charging
Substrate

- must be degradable
- must/should be available at a constant mass/volume flow
- should have a nearly constant composition
- Concentration of organic dry matter should be higher than 2%
- should be a liquid slurry
- Digester volume should be more than 100 m³
# Composition of manure

**Biogas potential: total organic solids (%)**

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Waste water, municipal</th>
<th>Waste water, food industry</th>
<th>Sewage sludge</th>
<th>Cow manure</th>
<th>Pig manure</th>
</tr>
</thead>
<tbody>
<tr>
<td>m³ CH₄/m³</td>
<td>0.05</td>
<td>0.15</td>
<td>2</td>
<td>8</td>
<td>6 to 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5 to 10</td>
<td>20 to 30</td>
<td>30 to 50</td>
</tr>
</tbody>
</table>

**Carbohydrates**

<table>
<thead>
<tr>
<th></th>
<th>Pig manure [%]</th>
<th>Cow manure [%]</th>
<th>Chicken manure [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrates</td>
<td>38</td>
<td>20</td>
<td>25</td>
</tr>
</tbody>
</table>

**Fat**

<table>
<thead>
<tr>
<th></th>
<th>Pig manure [%]</th>
<th>Cow manure [%]</th>
<th>Chicken manure [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**Protein**

<table>
<thead>
<tr>
<th></th>
<th>Pig manure [%]</th>
<th>Cow manure [%]</th>
<th>Chicken manure [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein</td>
<td>19</td>
<td>15</td>
<td>29</td>
</tr>
</tbody>
</table>

**Crude fiber**

<table>
<thead>
<tr>
<th></th>
<th>Pig manure [%]</th>
<th>Cow manure [%]</th>
<th>Chicken manure [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude fiber</td>
<td>20</td>
<td>40</td>
<td>15</td>
</tr>
</tbody>
</table>

**Ash**

<table>
<thead>
<tr>
<th></th>
<th>Pig manure [%]</th>
<th>Cow manure [%]</th>
<th>Chicken manure [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>19</td>
<td>21</td>
<td>27</td>
</tr>
</tbody>
</table>

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## Fertility and retention time

<table>
<thead>
<tr>
<th>Material</th>
<th>Biogas $m^3$/kg ODM</th>
<th>Retention time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>0.367</td>
<td>78 Days</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>0.501</td>
<td>14 Days</td>
</tr>
<tr>
<td>Haulm</td>
<td>0.606</td>
<td>53 Days</td>
</tr>
<tr>
<td>Corn</td>
<td>0.514</td>
<td>52 Days</td>
</tr>
<tr>
<td>Clover</td>
<td>0.445</td>
<td>28 Days</td>
</tr>
<tr>
<td>Grass</td>
<td>0.557</td>
<td>25 Days</td>
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</tbody>
</table>

Optimum substrate with:
- 70% manure
- 30% biomass

Impact parameters
Negative und optimum impact parameters

Substances with antibacterial impact:
– Heavy metals
– Mediums for the disinfection of stables
– Antibiotics for the animals

Optimum impact parameters:
Dry substance concentration: 3 % -10 %
pH-value: 6.5-7.2
Temperature impact on gas production

- **Mesophile**
- **Thermophile**

Temperature in digester

Gas amount per kg org. dry mass

Impact parameters

Temperature in digestor
Residence time

Biogas production

Impact parameters

Optimum

Mesophile bacteria: 20-25 days

Thermophile bacteria: 3-10 days
Substrate supply

\[ R_b = \frac{\dot{m}_{Su} C_{ODM}}{V_R} \]

- \( R_b \): volume load
- \( m_{Su} \): mass of substrate
- \( V_{Su} \): volume of substrate
- \( V_R \): reactor volume
- \( C_{ODM} \): concentration of organic dry mass

\( R_b \) indicates quantity in kg of organic dry matter loaded per day

- Complete digestion requires long residence time in the fermenter
- Long residence time require huge fermenters

\[ V_R \approx V_{Su} \]

\[ C_{ODM} = \frac{m_{ODM}}{m_{Su}} = \frac{V_{ODM} \rho_{ODM}}{V_{Su} \rho_{Su}} \]

Impact parameters
Substrate supply

\[ t_{Vw} = \frac{V_{Su}}{\dot{V}_{Su}} = \frac{m_{Su}}{\dot{m}_{Su}} \]

\[ t_{Vw} \approx \rho_{Su} \frac{C_{ODM}}{R_{b}} \]

**Example:** \( C_{ODM} = 0.08 \) substrate density: \( 1000 \text{ kg/m}^3 \)
residence time of the substrate: 20 days

\[
R_{b} = \rho_{Su} \frac{C_{ODM}}{t_{Vw}} = 1000 \cdot \frac{0.08}{20} = 4 \text{ kg ODM / m}^3
\]
Parameters of the biogas production

Cumulative production

Gas output

Volume load

Gas output

Cumulative production m³/kg ODM

Residence time  \( v_w \)

Cumulative production

[Graph showing parameters of biogas production]
Stirring device

Why stirring is necessary in the digester:

– Prevents sinking layers on the bottom of the fermenter
– Prevents swimming layers on the surface of the substrate
– Secures uniform temperature distribution
– Supplies bacteria uniformly with nutrients
Requirements

- A fermenter, supplied with bacteria (methanogens and decomposers)
- Moisture & anaerobic conditions
- Optimum uniform temperature of 35°C
- Optimum pH of 6.5 to 8
- Organic uniform waste (biomass) charging e.g. sewage, wood pulp
- C:N:P:S-ratio:

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<tr>
<td>Cow Dirt</td>
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<td>Bagasse</td>
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<td>Wood</td>
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<td>Pittsburgh Coal</td>
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Methanogens and the greenhouse effect

• Half of the methane produced by methanogens is used up as an energy source by other bacteria
• Half is lost to the atmosphere (600 M tonnes/a) where it acts as an important greenhouse gas
• As more land is converted to rice paddy fields and pasture for grazing animals more methane will be produced
Global warming

- As global warming progresses the permafrost with thaw in the tundra regions
- Tundra contains frozen peat
- As the peat warms and melts, it will provide a huge source of material for methanogens
- Methanogens will produce high amounts of methane
- Increase of methane in the atmosphere
- Further increase of global warming

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Impact parameters
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