Optimization of anaerobic digestion
by pretreatment, additives and process engineering

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Why and how to pretreat?

Why?
- 35% conversion efficiency of cattle manure is low
- 13% energy efficiency of biomass to electricity is weak

How to pre-treat?
- Mechanical pretreatment
- Chemical-Physical: Heat, ultrasonic, microwave, electrokinetic (BioCrack), acid, alkali, high-pressure steam expansion, ozone treatment
- Biological: Hydrolytic enzymes, Fungi, microorganisms
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→ Mild methods preferred
Methods are abundant. Finding the suitable pretreatment method

- Powerful enzymes for lignocellulose degradation to produce US biofuels (Genzyme)
- Ultrasonic treatment: 50 % more biogas from sewage sludge (Barber 2005)
- Ozone treatment of lignocellulose in manure (Sugimoto et al. 2009)
- Enzymatic digestion of switchgrass and manure (Wen 2004, 2008)
- Good results with ultrasonic treatment of fibre biomass (Chen 2008)
- German technology to pulverize every Nawao substrate (energy plants)
- Novel bacteria for hydrolysis and biogas production from maize silage
Swiss Substrates

Theoretical potential / used (in PJ)

- Cattle manure  47 / 0.6
- Green waste  10 / 1.1
  - Food industry  4.4 / 0.5
  - Sewage sludges  1.7 / 1.3
Goal: we want more gas!

We focused on substrates with mass potential in Switzerland

Manure and its fractions / sewage sludge / green waste

We focus on substrates with incomplete degradation

Green Waste / cellulose substrates / protein substrates

- We provide an independent overview of the effectiveness of chemical-physical pretreatment and their economic potential.
- We create a basis that allow an assessment of the use of enzymes in industrial scale.
- We provide a systematic comparison as basis for decision of new product development.
Example: Hydrolytic enzymes

- Catalyze reactions that would otherwise occur very slowly or not at all.

Fig. 1: Grass silage incubated with and without hydrolytic enzymes (cellulase + hemicellulases) for 15 h at 50 °C.
Thermal pretreatment steps are efficient, but must be adapted to the substrate. 15 - 20% higher gas yield is achievable.

Enzymatic effects are in the range of 5 % more gas yield, but they justify the use of enzyme mixtures barely.

Enzymes are proteins and not stable in a microbiologically active anaerobic environment.

By combination of heat and enzymes 25 - 30% gas yield increase is technically feasible.

If the economy is based solely on cost - benefit from biogas, the profit is marginal. With beneficial side-effects (residual heat use, sanitation, reducing viscosity) pretreatment may be beneficial.

Ecological footprint of pretreatment was not investigated here.
Downside trends are possible
Example of cow manure fractions

Past. = 70 °C
Electronic biogas production recording
Physical pretreatments are often not worth the energy that they need!
Cattle manure is resistant against mild physico-chemical methods

Physico-chemical pretreatment of cattle manure

- Ultraschall 15 kWh/m³: -16.3%
- Ultraschall + Wärme 70 °C: -6.3%
- Ozonierung (20 min): -2.8%
- Ozonierung (4 h): -0.4%
- Wärme 70 °C: -7.6%
- Wärme 121 °C: -7.6%
- Alkalische Hydrolyse 121 °C: -7.6%

Biogas-Mehr-/Minderertrag [%]
Conclusions

physico-chemical pretreatment

- High-temperature pretreatment at 70 °C - 121 °C show a lasting effect: they not only generate soluble material, but also lead to increased degradation.

- Other physical pretreatments, such as ultrasonic treatment, showed mainly positive effects with cellular substrates i.e. with sewage sludge.

- Cattle manure and their fractions showed extreme resistance to all chemical, physical and mechanical pretreatments. With mild methods, increased gas yield was not realized.

- The achievable energy conversion due to improved digestion and degradation usually does not cover the energy required for pretreatment.

- In thermal pretreatment steps, the heat must be recovered.
Also valid for enzyme treatment:
Cattle manure is a resistant substrate
Enzymes can do it better, but the effect is not necessarily maintained!

Time dependence of the methane yield from green waste silage
Enzymes are unstable in the fermenter!

Saccharides release from pasteurized silage by enzymes
Conclusions enzymes

- Commercially available enzyme mixtures are optimized for Nawaro and therefore not really suitable for organic waste substrates.
- Cattle manure and their fractions are very resistant to enzymatic digestion.
- Cellular and cellulose-containing substrates are suitable for the use of enzymes. 15 – 20 % increased methane yield is possible.
- The sales returns from additional methane by enzymes barely covers the costs.
- Enzymes and enzyme mixtures are not stable in biogas plants. Their activity is limited to hours, then they become inactive, or they are broken down by the anaerobic population.
- For the specific use of enzymes in the biogas process, a separate stage with optimized conditions is essential (pH, temperature, sterile).
Fazit: 1/3 more gas is feasible

Results from sewage sludge treatment
Pretreatment yes, but for what price?

- The benefits should exceed the costs by a factor of 3
- e.g. for 10% more methane yield from cow manure the cost for pretreatment must not exceed 0.35 CHF / ton.
- Use heat when it is free (the higher the temperature the better)
- Hygienisation by heat is only profitable with high-energy substrates
Process engineering: For manure fractions (liquid/solid) selected pretreatment methods are applied on a larger scale and in separate compartments. Separation of hydrolysis from methane reactor.

The possibility of inclusion of long-term medium-level heat is examined.

The effect of heat on digestion and the methane yield from food waste is described.

The electrokinetic disintegration of municipal sewage sludge and other biogas substrates is being carried out on a pilot plant scale.

Life cycle assessment of pretreatment methods is needed.

Pretreatment has potential!

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