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Two stage anaerobic digestion system: Hydrolysis of different substrate

Due to different growth rates, preferences and requirements of the involved microorganism species of each step, physical separation in two independently performing reactors (two phase anaerobic digestion (AD) system) is an option to enable specific conditions for the microbiology. The aim of this study is to control the amount of formed volatile fatty acids by adjusting the pH value in the hydrolytic reactor of a two stage AD system. The acids could be temporary stored and used for need-based biogas production according to the power demand.
The results obtained in this work for two different substrates show that the higher the pH value of the hydrolytic stage the higher the acids production and the degree degradation of both substrates. In tendency, the persistent fraction including hemi-cellulose and cellulose is more effectively degraded at high pH value. The methane content reached 80 % of the gas composition.

Keywords
Hydrolysis, pH value, acid production, two stage anaerobic digestion system

Abstract
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Conventional single-phase systems for biogas production have a limited scope for maintaining process stability or adapting the microbiology to changing substrates. The acid production and degradation must be in equilibrium in order to avoid uncontrolled acidification or failure to exploit the full capacity of the process. After all, optimal exploitation of the substrates used is a basic prerequisite for successful plant operation.

In the anaerobic digestion process, hydrolysis is often the limiting phase when degrading substrates which are difficult to decompose, while in the degradation of easily decomposable substrates methanogenesis is the limiting phase [1; 2]. Product inhibition or acidification of the system can develop during digestion of fast degradable substrates and cause an additional impediment to methane gas formation. On the other hand, the process is under-exploited when digesting substrates that are difficult to degrade, as the hydrolysis itself is the limiting phase of the process.

By physical separation of the hydrolysis/acidogenesis (hydrolytic reactor) from the acetogenesis/methanogenesis (methane reactor), it would be possible in principle to adapt the process conditions to the specific needs of the microbiology. Fibre-rich substrates could be degraded more quickly in the hydrolytic reactor, which would accelerate the production of dissolved organic carbon, for example acids.

The amendment to the German Renewable Energy Act has made both the use of fibre-rich substances and direct feeding of biogas into the natural gas grid increasingly more important. At the same time, to facilitate further expansion of renewable energies it is necessary to be able to satisfy fluctuating peak loads in the electricity grid.

This research work focuses on the digestion of two substrates in a two-phase biogas process, one which is difficult to degrade and one which is easy to degrade. In this process,

- maximum degradation of acids is to be targeted in the hydrolytic reactor so that they can be stored until required for biogas production on demand;
- conversion of the acids into biogas with a high methane concentration (75–80 %) is to be targeted in a downstream methane reactor. This could contribute to a further lowering of costs for conditioning the biogas for feed in into the natural gas grid.

Potential advantages of two-phase systems:

- The desired acid concentration can be adjusted in the hydrolytic reactor and transferred to the methane reactor in line with needs.
- A high methane content can be achieved in the produced biogas.
- When different substrates are used, high organic loading rates are possible without causing instability of the system.

Material and method

The experiments were conducted in two two-phase continuous-flow systems, each consisting of a hydrolytic reactor with 40 l and a methane reactor with 70 l working volume. Both hydrolytic reactors were operated thermophilically; different organic loading rates were selected (**Table 1**).

Daily the substrate was removed from the hydrolytic reactor and was separated into two fractions: the solid phase containing the structural substances still undissolved after hydrolysis, and the liquid phase (hydrolysate), which chiefly contains dissolved substances, predominantly acids. The hydrolysate served solely as substrate for feeding the methane reactor. The buffer capacity in the hydrolytic reactor was adjusted using sodium hydrogen carbonate ($NaHCO_3$).

Substrates

The substrates used consisted of a straw and hay mixture (50/50 % by weight) and easily digestible 100% maize silage. The substrates were reduced to chop lengths of 4 mm for both experiments.

Previous batch experiments conducted at our institute showed that compared to hydraulic retention time, organic loading rate and temperature the pH value has the strongest influence on degradation during hydrolysis/acidogenesis [3].

For this reason the influence of different pH values on hydrolysis of the two substrates was examined in continuous flow operation. The acid concentration and the degree of degradation (related to oDM) were used as parameters to assess the hydrolysis efficiency. For the straw-hay substrate the pH value in the hydrolytic reactor was varied between from 5.2 to 7.0. The pH value range examined for hydrolysis of the maize silage ranged from 4.7 to 5.9. A key requirement for the hydrolytic reactor operation was that the produced biogas should have the lowest possible methane content, as the conversion of the liquefied organic fraction was to be carried out specifically in the methane reactor.

Results

Hydrolytic reactor

During the hydrolysis and the subsequent acidogenesis, the substrate is liquefied. When adjusting the pH value in the hydrolytic reactor, the influence of the pH level on both the degree of substrate degradation and the acid formation was measured. **Figure 1** shows the substance-specific degradation of the straw-hay mixture (left) and the maize silage (right).

The data were calculated using the results of the Van-Soest fraction analysis and stated in % oDM relative to the input material. The degree of degradation is defined as the share of liquefied organic substrate in the hydrolytic reactor. The results show a differing degradation of the individual substrate fractions in both treatments depending on the pH value in the hydrolytic reactor. A rise in pH value induced an increase in acid concentration, expressed as acetic acid equivalent, and a higher level of degradation in both treatments [3]. However, the highest degradation level of 30 % measured for the straw-hay substrate (left) at a pH value of 6.7–7.0 was distinctly lower than in a single-phase continuous flow system, where a degradation level of 60 % was achieved for the same substrate [4]. Again the liquefaction of the straw-hay mixture turned out to be the limiting phase for this process. The degree of degradation of 30 % was achieved with a shorter hydraulic retention time than in the single-phase continuous flow system.

For the maize silage, a degradation level of 74 % was achieved at a pH value of 5.9. While acid concentrations of 10 g kg^{-1} were achieved at pH values around 7.0 for the straw-hay mixture, concentrations of more than 20 g kg^{-1} were obtained at pH values of around 5.9 in the maize silage treatments.

It has to be noted that the pH value had no influence on the degradation of the easily degradable ingredients of both substrates (for example starch and sugar). On the other hand, a rising trend was noted in the degradation of the hemicellulose and cellulose, which were better converted at rising pH values.

Methane reactor

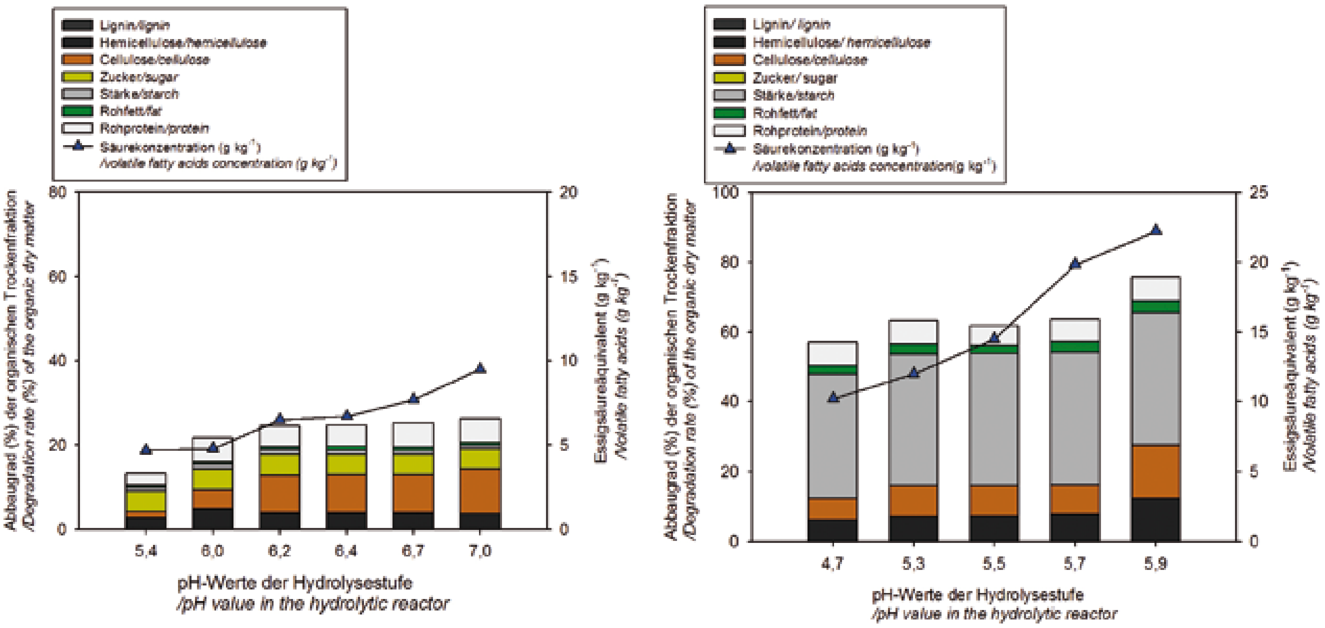
Table 1

Operating parameters of the experiments with a straw-hay mix and with maize silage

	Raumbelastung ***Organic loading rate*** $kg_{oTS}\ m^{-3}\ d^{-1}$	**Maximale Säurekonzentration**[1] **in die Methanstufe überführt** ***Maximum acids concentration***[1] ***load to methane reacto*** **g Essigsäureäquivalent** d^{-1} *g Acetic acid equivalents* d^{-1}	**Temperatur Hydrolysestufe** ***Temperature hydrolytic reactor*** °C	**Temperatur Methanstufe** ***Temperature methane reactor*** °C
Stroh-Heu-Mischung/*Straw-hay mix*				
	3,5	20	45	38
Maissilage/*Maize silage*				
	8	44	55	38

[1] Säurekonzentration in der Hydrolysestufe bei pH-Wert 6,8 (Stroh-Heu) und pH-Wert 5,9 (Maissilage)/*Acids concentration in the hydrolytic reactor at pH value 6.8 (straw-hay) and pH value 5.9 (maize silage).*

Fig. 1

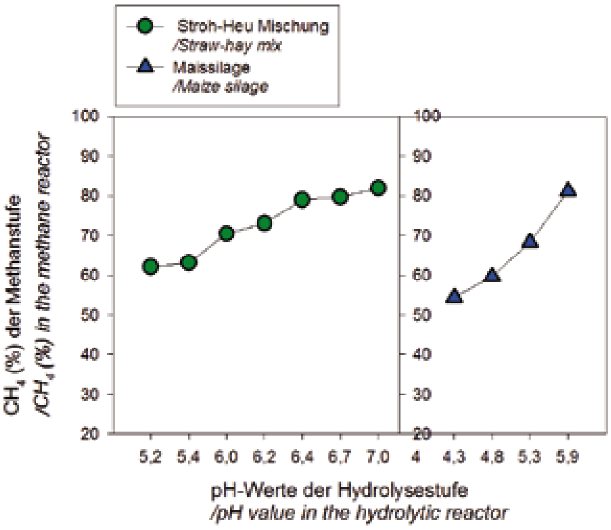


Degradation of the substrate in the hydrolytic reactor of a two stage system, straw-hay mix (left), maize silage (right)

After the liquefied organic fraction (hydrolysate) is transferred to the methane reactor, it is converted completely into methane-rich gas. For both substrates **Figure 2** shows the methane content in the biogas at different pH values within the hydrolytic reactor.

The increase in methane content with rising pH value or rising acid concentration, respectively, was observed for both hydrolysates, the straw-hay mixture and the maize silage. For the hydrolysate from the straw-hay mixture, the highest methane content (approx. 80 %) was achieved at a pH value of 6.8. Above this pH value the acids had already converted into methane in the hydrolytic reactor and thus could not be separated from this reactor and transferred to the methane digester. Experiments conducted with maize silage in the two-phase continuous flow system showed comparable developments in the methane content.

Fig. 2



Methane content in the methane digester for the straw-hay mix and for maize silage

Conclusions

A key aspect of the experiment was to establish an efficient hydrolytic reactor to digest fibre-rich substrates. Microbiology adapted milieu conditions in two-phase continuous flow systems are comparable with those in single-phase continuous flow systems. This applies in particular to the pH value. Further degradation of the cellulose-hemicellulose in the hydrolytic stage is possible at pH values above 7.0, but this would also result in methane formation and thus a conversion of a two-phase process into a single-phase process.

By contrast, high degradation levels are possible at lower pH values for substrates that are easy to digest, allowing an intermediate storage in the form of acids. This unlocks potential for converting the acids into biogas and subsequently into electricity in response to fluctuating electricity demand. As the biogas thus obtained already displays methane concentrations of up to 80 %, it would enable cost reduction for gas conditioning. This would be a next step in the direction of a decentralised solution for renewable electricity supply using biogas.

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