Zielonka, Simon; Lemmer, Andreas; Oechsner, Hans and Jungbluth, Thomas

Two phase digestion of renewable raw materials – comparison of different substrates

The use of renewable raw materials with a high fibre content, like grass silage, as a co substrate in full scale biogas plants is causing technical problems. Within the framework of this project, a process allowing the digestion of renewable raw materials as single substrates is being developed. Its aim is to optimize the milieu conditions for the different micro-organisms implicated in the biogas process by a two phase process. Therefore a discontinuously operated two phase lab scale biogas plant is used. In the research presented here the applicability of this process for different renewable raw materials was evaluated.

Keywords

Batch-Digester, biogas, fixed bed reactor, grass silage, maize silage, rye silage, hydrolysis, methane, percolate, two-stage

Abstract

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In 2015, approximately 26% of the grassland areas of Baden-Wuerttemberg will no longer effectively be used for fodder production [1]. There is therefore a great interest in a technical way to exploit this energy without the use of manure. But the high fibre content of the grass limits so far the energy use in agricultural biogas plants. For this reason, the University of Hohenheim researched under the joint research project „Biogas Crops Network“ along with ten institutions nationwide [2] the basics of biogas production from biogas crops and in particular the mono fermentation of grass silage in a two-phase process management using a batch percolation hydrolysis.

State of knowledge

The incomplete anaerobic mineralization of biomass and its conversion to biogas is carried out in four stages by a variety of microorganisms. These microorganisms reach their optimum at very different environmental conditions. The optimum pH range of the bacteria which start the anaerobic conversion of biomass is between 4.5 and 6.3. The methanogenic microorganisms achieve their metabolic optimum between pH 6.5 to 8 [3]. Thus the formation of acid is in single-stage biogas digesters sub-optimal. Also the temperature requirements are different: for example, in a fermentation operated at 55 °C a significantly better degree of degradation and methane yields were achieved in a shorter time than at lower temperatures [4].

Objective

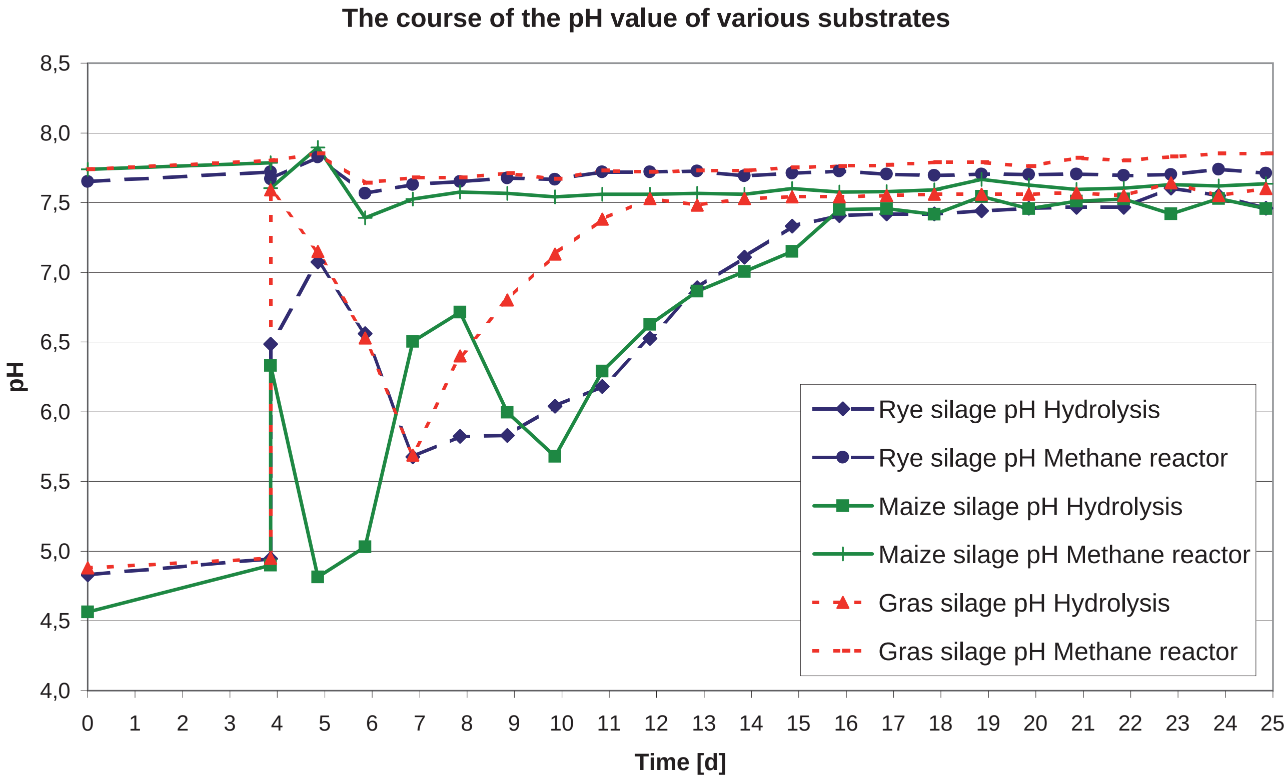
The aim of the research project at the State Institute of Agricultural Engineering and Bio-energy is to divide the process of biogas production by procedural measures in a phase of fermentation (acidification) and a phase of methanogenesis. This two phase process control is designed to better meet the living conditions of the microorganisms and to accelerate the process. In the frame of the research presented here, the influence of various substrates on the process as well as the possible biogas yields should be investigated. Therefore various silages are used as substrates in the two-phase lab scale biogas plant.

Materials and methods

The experiments are carried out in the Solid Substrate Biogas Laboratory of the University of Hohenheim. The experimental plant consists of five fermenter pairs with a volume of about 50 liters for each fermenter. Each pair consists of a batch percolation fermenter for acidification („hydrolysis fermenter“) and a quasi-continuously fed up-flow fixed bed reactor for the methane production. In the hydrolysis fermenters the solid substrate is transformed during the hydrolysis and acidogenesis to acids and alcohol, which are then washed out of the substrate stack with the percolate (bioleaching). This percolate highly loaded with organic material is transferred to the methane reactors (fixed bed) once a day. There, the organic fractions of the percolate are converted into biogas.

In the trial three common biogas substrates – grass silage (1. cut, intensive use of grassland), corn silage and rye silage – were compared. All the „hydrolysis fermenters“ were filled at

Fig. 1



The development of the pH-values of the substrates grass silage, maize silage and rye silage in a two phase process with a batch hydrolysis

test start with 1 kg organic dry matter of silage. Subsequently 10 kg of tap water was added to these fermenters. The fixed-bed methane reactors (pH about 7.5) are filled with growth bodies for the microorganisms and 45 l percolate. After the filling follows a four-day start-up phase in which the hydrolysis fermenters are percolated internal and no percolate is exchanged between the hydrolysis and methane phase. After this initial phase 3,25 kilograms of percolate are exchanged daily between the fermenters. The experiment presented here ended after the gas formation which lasted 25 days was completed.

In the experiments both the substrate and the fermentation residue are tested for the maximum biogas yield, the groups of substances, the organic and mineral nitrogen content and the dry matter content (DM content). In the process fluid pH, electrical conductivity, volatile fatty acids, COD, DM content and the temperature are tested. The biogas yield and the components of the biogas, CH_4, CO_2 and H_2, are captured separately for each phase. This enables the determination of the distribution of the methane production on the various phases.

Comparison of the suitability of different substrates for the two-phase fermentation using batch hydrolysis

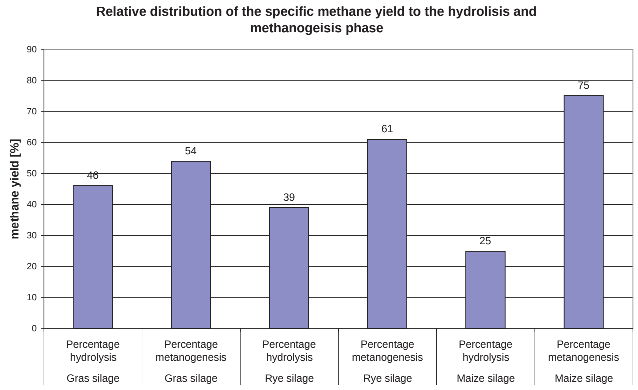
The used substrates – maize silage, rye silage and grass silage – showed an individual behaviour during the fermentation process. In **figure 1** the pH of the percolate measured over the experimental time at the drain of the „hydrolysis fermenters“ and of the methane reactors are presented. At start all substrates had pH values between 4.5 and 5. Until the percolate was exchanged for the first time between the phases the pH values remained relatively stable. After the first exchange of process fluid between the phases at day four of the experiment a sudden increase in pH caused by the mixing of liquids with different pH values is reported. While the pH-Values of the corn silage dropped quickly under 5 again, the values of the grass and rye silage only reach a pH of 5.6. Then the pH values of the grass silage rise much more rapidly in the hydrolysis fermenters than the ones of the other substrates, so that the pH value of 7.5 is reached four test days earlier (**figure 1**). In the pH curve of the corn silage an intermittent increase of the pH is detected between the sixth and tenth experimental day. This is related to the acetic acid formation of maize silage. This reached its maximum only in the experimental day ten, while the maximum of the other variants are observed in the experimental day seven. Although the acetic acid equivalents of the investigated substrates reached a maximum of nine g / kg in the hydrolysis fermenters, the values of the grass silage fall much faster than the ones of corn and rye silage.

The slower increase of the pH value of corn and rye silage in the „hydrolysis fermenters" prevents the formation of methane in these fermenters, whereby a higher proportion of methane is formed in the methane reactors (**figure 2**).

The corn silage provides the highest biogas and methane yields with 779 and 362 lN / kg VS followed by rye silage with 665 and 347 lN / kg VS and grass silage with 334 to 645 lN / kg VS (**table 1**). While the average methane content of the biogas formed in the „hydrolysis fermenters" varies greatly depending on the substrates used, the average methane content of the biogas of the methane digesters is in all variants with 72 or 76% relatively stable. The high methane yield of corn silage in the methane reactors seems to not affect strongly the quality of the gas.

The experiments show a stable fermentation despite sudden substrate changes. Through the longer acid replication at the maize and rye silage compared to grass silage the pH value remains longer in a more favourable range for the hydrolysis. Thus, the methane production can be prevented in the hydrolysis fermenters, so that a better separation of the phases is achieved. So a different suitability for a two-phase fermentation using batch percolation hydrolysis could be observed for the analysed substrates.

Fig. 2



Relative distribution of the specific methane yield of the various stages (hydrolysis and methanogenesis) in the two-phase anaerobic digestion of various renewable resources

Literature

Books are marked with ●

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Authors

M.Sc. agr. Simon Zielonka is a research associate at the State Institute of Agricultural Engineering and bioenergy (formerly: State Institute of Farm Machinery and Construction) at the University of Hohenheim, Garbenstraße 9, 70599 Stuttgart, E-Mail: zielonka@uni-hohenheim.de

Dr. Andreas Lemmer is a researcher at the State Institute of Agricultural Engineering and bioenergy at the University of Hohenheim, E-Mail: lemmeran@uni-hohenheim.de

Dr. Hans Oechsner is head of the State Institute of Agricultural Engineering and bioenergy at the University of Hohenheim, E-Mail: oechsner@uni-hohenheim.de

Prof. Dr. agr. Thomas Jungbluth is head of the Department of Livestock Systems at the Institute of Agricultural Engineering, University of Hohenheim, Garbe Strasse 9, 70599 Stuttgart, E-Mail: jungblut@uni-hohenheim.de

Tab. 1

The specific biogas and methane yields of different substrates and their distribution to the hydrolysis and methanogenesis phase of a two phase digestion process.

		Gras silage	Maize silage[1]	Rye silage[1]
Specific biogas yield of the entire plant[2]	[l_N/ kg oDM]	645	779	665
Specific methane yield of the entire plant[2]	[l_N/ kg oDM]	334	363	347
Average value of the methane content of the hydrolysis fermenters	Vol%	39	27	33
Average value of the methane content of the methane reactor	Vol%	76	72	76
Percentage of the hydrolysis fermenters of the total methane yield	%	46	25	39
Percentage of the methane reactors of the total methane yield	%	54	75	61

[1]Values are the means of repeats; [2]The biogas and methane yield values are not fermentation acids corrected