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Extension of the raw material basis for the production of biogas through an efficient conversion of biomass

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Abstract. The raw material base for biogas production shall be enlarged considerably by biomass processing that is efficient economically and in terms of energy consumption. At present, maize, whole plant corn silage and dung are of use primarily for the production of biogas. Since neither monocultures nor food competition are desirable, the research and development is focused on the expansion of raw materials such as beta beets, including beet leaf and lignocellulosic biomass, e.g. straw, dung, grassland cut and landscape management material.

The raw materials are crushed and frayed out with special technologies to accelarte hydrolysis in the biogas process. By this process further renewable raw materials can be used for fermentation, shortening the time for fermentation and increasing biogas yield. Moreover, the technology reduces cost because straw, dung and landscape management material, for example, are more reasonably priced than cultivated biomass. Furthermore positive influences on crop rotation, the reproduction of soil fertility and the conservation of nature can be expected.

Key words: biogas, process technology, two-step process, hydrolysis, biomass digestion / steam explosion, hydrolysis optimization

INTRODUCTION

About 4.000 biogas plants operate in Germany. Most of these plants use a conventional wet fermentation process based on co-fermentation of the following inputs:

- manure – silage of maize – whole corn

or

- manure – silage of whole cereal plants – whole corn.

The international trade for agricultural products has grown substantially according to the steadily increasing demand for products such as cereal, especially wheat, maize and rape seed and the parallel demand on renewable resources for the production of goods and energy services. Some of the above-named inputs are used in digesters to produce renewable energy as well this, however, also increases the pressure on

agricultural production as a whole but on soil in particular (Dr. A. Vetter et al., 2008; Dr. C. da Costa Gomez, 2008).

On the other hand, about 20 to 30 per cent of the grasslands are no longer in use. Cattle are fed maize silage which is rich in proteins and easy to digest instead of grass or grass silage previously used in cattle fodder.

This paper intends to explore opportunities using lignocellulosis in biogas plants. One may view lignocellulosis as a highly competitive resource because of low prices. Input materials evaluated in this paper fulfil the conditions of Cross Compliance mentioned in the EU Directive 795/2004, namely, grass and grass silage grown on permanent grass land or materials from landscape management as well as straw, straw dung or other by-products from arable land that are rich in fibres.

MATERIALS AND METHODS, RESULTS AND DISCUSSION

Using silage rich in lignocellulosis in a two-step fermentation process. Biogas production is characterised by a four-phase process as distinguished in Fig. 1, below. All four phases occur in one single reactor in parallel. A distinct group of bacteria drives the processes in each step.

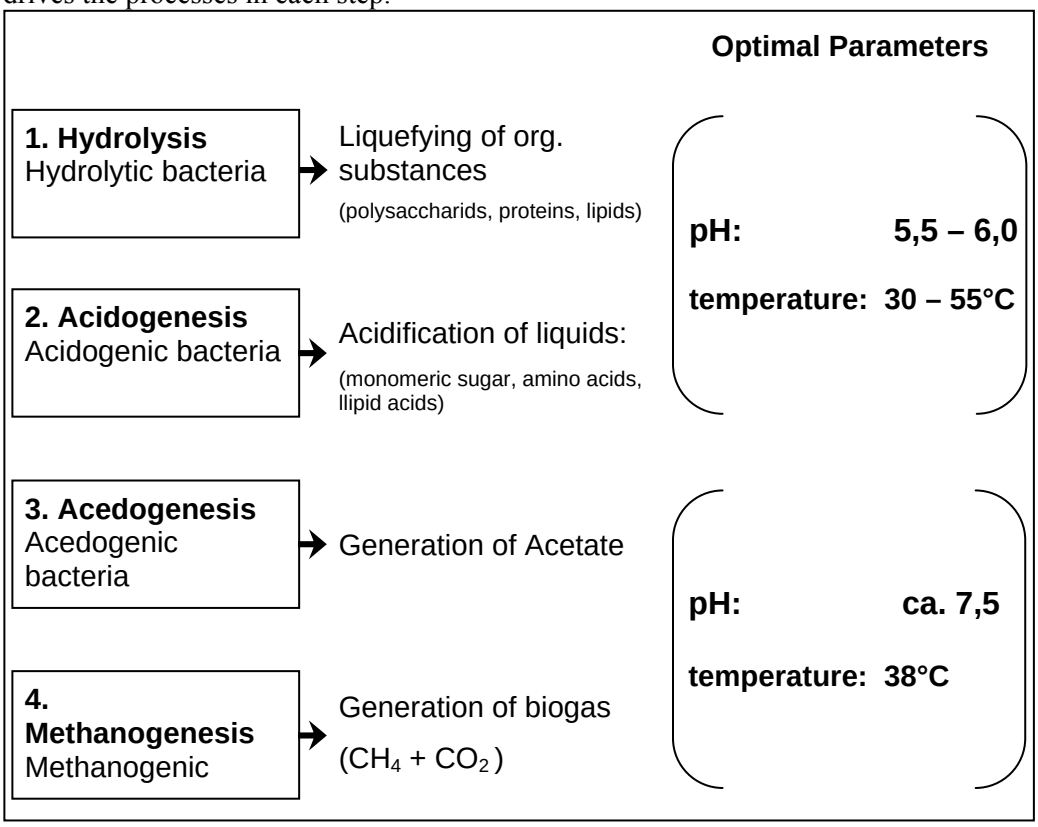

Fig. 1. The four fermentation process steps (according to Busch et al., 2007; Zilonka et al., 2007).

However, micro-organisms demand very specific process conditions to do their work most efficiently. Consequently, there is no reactor that allows for optimal conditions for all of the bacteria groups and hence for all four process steps (Busch et al., 2007; Zilonka et al., 2007) at the same time. Moreover, the reaction times of each of the four phases differ. Hydrolysis determines the velocity of the overall process of the digestion, particularly when the silage in use is high in lignocellulosis. The C_6-sugar containing cellulosis microfibres are well protected by the complexes of lignocellulosis. Hemicellulosis or lignin embed lignocellulosis and therefore the cracking of the lignocellulosis complex requires a variety of enzymes and a residence time in the reactor that is much longer than in methane genesis. This non-compliance of reaction times causes a high volume of non-digested residues. Consequently, the residues of the digestion still contain a high content of organic dry material. This in turn results in a low economic efficiency of fermentation plants, especially those which are using materials that are rich in lignocellulosis.

A two-step dry-wet-fermentation tries to optimise between a high exploitation rate for the organic dry material and the residence time in the reactor. The main target is to enhance the capacity of the hydrolysis to increase the overall flow rate (Bischofsberger et al., 2005; Busch et al., 2007; Zilonka et al., 2007).

The two-step process uses so-called percolators for the first two steps of the biogas production, i.e. hydrolysis and acidogenesis (Fig. 2). Solid and biomass, rich in lignocellulosis, is mixed with conventional enzymes during the first two process steps. The enzymatic reaction liquefies and acidifies this mixture and results in a hydrolytic intermediate product. This intermediate product is fed back and sprayed into the reactor as long as the digestion of the input material results in an almost 80 per cent conversion of the inputs. Digestion takes place in an optimised sour environment and demands a relatively short residence time. The hydrolytic intermediate product is continuously treated by separation into a liquid and a solid fraction during the circulation. The separation assures that high levels of CSB could be avoided (40.000 mg CSB/l). A high CSB value may inhibit the hydrolysis. Only the liquid fraction will be supplied to the methane genesis reactor. The solid fraction is diluted in water and sprayed into the percolators again.

The methane reactor contains granules. Methanogenic bacteria grow on the surface of these granules. The bacteria convert the intermediate hydrolysis product into biogas at a high rate. One may influence the intensity of the methane genesis using an intermediate storage tank for the hydrolysis product. This allows adapting the flow rate to the methane reactor and thus the conversion rate into methane. The CO_2 – a by-product acidogenic phase – is separated from the gas stream before the hydrolysis product enters the methane generating reactor. Therefore, the methane content of the resulting biogas is comparatively high, almost 75 per cent.

This modular concept of such a biogas plant allows using different silage material or different quality of the silage – varying proportions of lignocellulosis – since the residence time as well as the circulation flow of the intermediate hydrolysis products can be influenced.

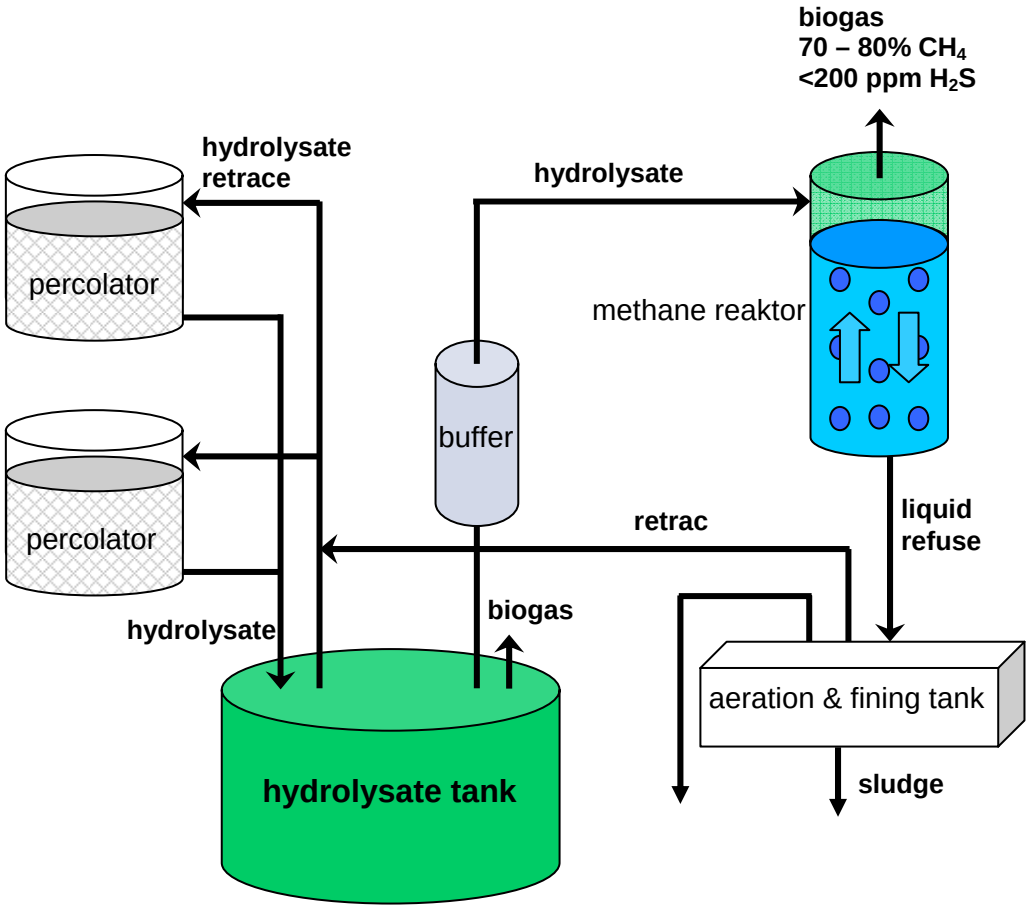

Fig. 2. The two-step biogas process (according to Busch et al., 2007).

Using silage rich in lignocellulosis after hot pre-hydrolysis. A hot pre-hydrolysis may shorten the residence time in the reactor since it makes the destruction of the very stable lignocellulosis complex considerably easier and faster for old grass, straw or other comparable input materials. The hot pre-hydrolysis would be the first step in the process. The process of hot pre-hydrolysis has been developed at the Technical University of Wismar (Schmidt, 2003) and is based on a high pressure – steam – explosion process (Fig. 3).

The input material is treated as follows: steam exposition, heating to about 170°C with increasing pressure up to about 8 bar followed by a sudden controlled explosion. The process makes hemicellulosis, especially C_5-sugar, readily soluble. Lignin stays loose-bounded at the cellulosis fibres and cellulosis itself is weakened at least in its non-morphologic structure. Moreover many cells are destroyed. The former solid biomass is liquefied and ready for pumping (Heitz et al., 1991; Bobleter et al., 1998; Kažemėkas, 2005; Kažemėkas et al., 2006).

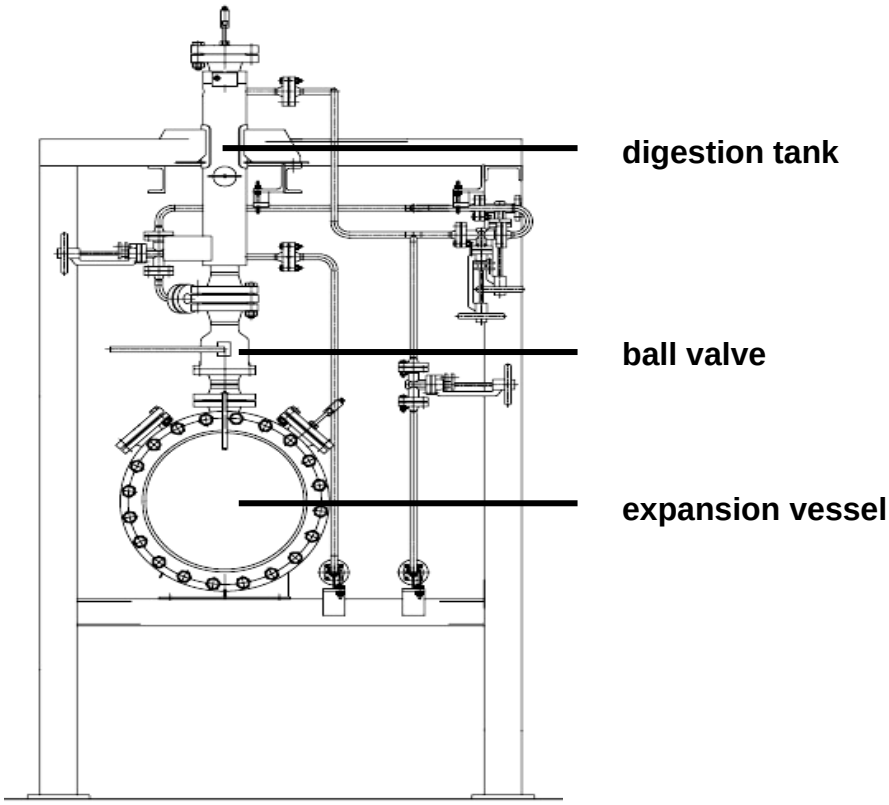

Fig. 3. The high pressure – steam – explosion construction.

One may gain a similar effect when using a heated double screw extruder assembled to a pressure vessel (Fig. 4).

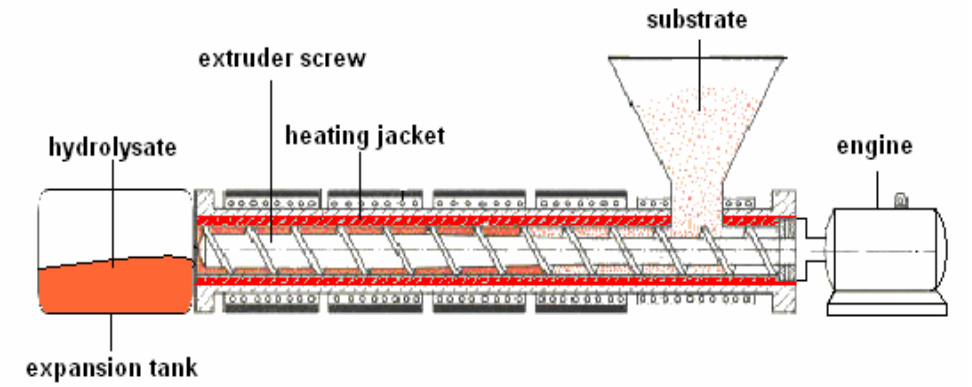

Fig. 4. The heated double screw extruder with a pressure vessel.

The extruder screw crushes the lignocellulosis-rich material into fibres. This destruction results in a material structure that is characterised by an increased and absorbent surface. Since the fibres may absorb steam and heat more easily, the efficiency of the short term hydrolysis process increases. The specific process parameters for the pre-hydrolysis depend on the species of silage. More importantly, it is possible to use or prepare any kind of biomass for efficient and economically feasible biogas production when applying high pressure – steam – explosion or double screw extrusion.

The hot pre-hydrolysis allows for a short hydraulic residence time of about 15 days without adding specific enzyme mixtures for both the hydrolysis and the acidogenesis phase. This also applies for material that is very rich in lignocellulosis. The succeeding acido- and methano-genesis phases are the most efficient if handled in a separate methano-genesis reactor using a pH level of 7.8 and a temperature level of 38°C.

Two biogas plants on a pilot scale, consisting of six fifty-litre reactors each, are in use at the Technical University of Wismar. The company Stirl-Plant Technology has delivered the two pilot plants (Fig. 5). Each plant is equipped with separate mixers, gas counters, pH measurement and PC control. One has a choice between using each reactor as one-step, hydrolysis or methano-genesis digester.

Fig. 5. The biogas pilot plant.

The size of the reactors allows for research but also assembling tests that allow for direct up-scaling of the plants as well as assessing the economic feasibility and viability of biogas production from materials which are rich in lignocellulosis.

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