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Digestion of Agricultural Substrates in Discontinuous Solid-phase Fermentation Systems

Using solid materials to produce biogas becomes more and more attractive in agriculture and interest in special solid-phase digestion systems is high. In agriculture mainly batch operated solid-phase processes with percolation are favoured. Experimental results show, that in such systems digestion of materials with high energy content demands the use of a high ratio of solid inoculum. Substrates with a tight structure should be mixed with structure material before digestion.

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Keywords

Biogas, solid-phase fermentation, dry fermentation

Literature

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In agricultural biogas production liquid-phase digestion is mostly applied today. Slurry was the predominant agricultural substrate over many years, therefore research and technology development in agricultural biogas production have long concentrated on liquid-phase digestion systems. In the field of municipal waste treatment, in general a solid substrate has to be treated, so the development of solid-phase digestion systems was a logical step. In 2004 in Germany 47 % of the digested municipal organic wastes were treated in solid-phase digestion systems [1].

Digestion of solid substrates in liquid-phase systems is restricted. With high content of total solids (TS), problems occur especially regarding the technique for mixing the substrate within the reactor as well as with the fermenterís charging and discharging technique. Some substrates are totally not suitable for liquid digestion, e.g. materials with a higher amount of woody fractions or those containing stones, which is likely the case for green cut. Therefore in agriculture interest is increasing to apply technologies that allow the digestion with higher contents of total solids and possibly without adding liquid manure. In general one uses the terminology „dry digestion“ to characterise this process. Considering the fact that actually dry digestion is not possible, in this study the term „solid-phase digestion“ is used instead.

There is no doubt that methanogenesis of organic materials is possible in digesters with higher contents of total solids. Nevertheless substrates have to be tested under the specific conditions of a particular system. In contrast to the municipal field, where continuous digester types are mainly found, in agriculture a tendency towards discontinuous low cost systems with a robust technology and a high flexibility can be observed. In these systems the reactors are filled with stacked substrate and then closed. The substrate batch is digested over several weeks. Then the reactor is opened and emptied, before the next substrate batch is filled in. Because of the changing gas quality and quantity during a cycle, several reactors have to be run parallel, in order to attain an even gas production of the whole installation.

Project objectives and methods

The solid-phase digestion of agricultural substrates in discontinuous fermenters with percolation (sprinkling of process water over the biomass) is the topic of an ongoing research project at the University of Hohenheim. A combination of laboratory and farm scale experiments is conducted in order to identify the conditions that enable a stable fermentation of different substrates.

A laboratory with 10 „solid-phase“ laboratory-scale reactors has been built up. *Figure 1* shows the design of a reactor. Material in the fermenters can be percolated or flooded with process water. The reactors also provide the possibility to aerate the substrate.

The full-scale farm plant consists of 4 digestion boxes with an individual volume of approximately 130 m^3 each, of which 100 to 110 m^3 can actually be filled with substrate. During the digestion, process water is sprinkled discontinuously over the biomass. The leachate of all four boxes is collected in one process water tank and reused for percolation. The plant was built mainly for the digestion of green cut collected by the municipality. Other materials like dung or energy plants are used as well. The digestion plant is described in [2].

Table 1: Necessary ratio of solid inoculum for digestion of various solid materials in the percolation process

Substrate	Necessary ratio of solid inoculum (w/w TS)
Cow dung	0 %, but augmentation of gas yield after addition of structure material
Horse dung with straw	10 to 20 %
Ensiled gras	around 70 %
Ensiled forage maize	around 70 %

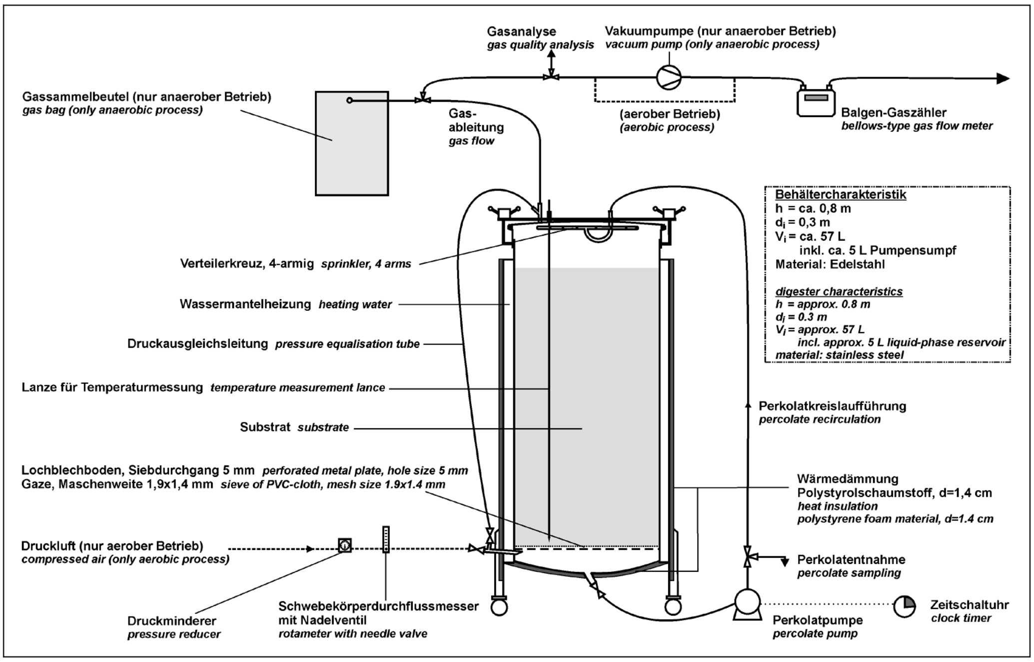

Fig. 1: Laboratory-scale solid phase digester

Results on green cut digestion

Chopped green cut with a high proportion of woody material was digested in the laboratory system at the temperature of 35°C. The green cut (TS 46.3 % w/w [weight in weight], VS/TS 61.7 % w/w) came from the farm-scale plant and was collected by the municipality between end of May and beginning of July 2004. Two parallels of every experimental version were set up: percolated (twice daily for 15 min), flooded with process water and percolated in a mixture with 25% v/v [volume in volume] solid inoculum (TS 35.3 % w/w, VS/TS 40.5 % w/w; digested green cut with a small ratio of digested cow dung). The solid inoculum was digested separately in order to determine its methane yield for later calculations. *Figure 2* shows methane yields and pH-values of the test cells in the experiment. It has to be considered that in the mixture with solid inoculum the total methane yield is the sum of the methane yields from three components: green cut, solid inoculum and process water. The methane yield from the component green cut can be determined by calculation [2]. The resulting methane yield of the component green cut was 88.3 LN CH_4/kg VS.

In the test cells with percolated green cut (with no solid inoculum) a rapid acidification occurred and the pH remained under 6 during the first two weeks. During this period methane production was inhibited. In the flooded test cells the pH did not drop under 6 and the initial methane production was fast. After subtraction of the methane yield originating from the process water, the me thane yield of the component green cut in the flooded mode was 90.2 LN CH_4/kg VS after 6 weeks. This is very similar to the digestion in mixture with 25 % solid inoculum in the percolation mode. This means that flooding did not lead to a higher methane yield from the component green cut. But because no addition of solid inoculum was necessary, the energy density in the fermenter and therefore the gas production per reactor volume were higher.

Results on substrate conditioning

In order to avoid too strong acidification of a batch during digestion, the fresh substrate has to be mixed with solid inoculum (already digested material). While digestion of solid dung requires only small ratios of solid inoculum, the use of materials with high energy density like energy plants requires mixing with high amounts of already digested substrate, see *table 1*.

In the percolation process it is important to have a substrate body, where the process water can really trickle through. On the one hand the viscosity of the process water should be low. On the other hand the substrate must contain a sufficient amount of structure material. In laboratory experiments cow dung was digested as mono substrate and in mixture with green cut as structure material in a ratio of 50% (v/v). Adding the structure material lead to a 50 % increase of the methane yield (of the component cow dung) compared to the mere cow dung as mono substrate [2]. Both fresh green cut and already dige-sted green cut showed the same effect.

Conclusion

All experimental results are substrate specific, meaning that the prediction for other materials is difficult. For example the necessary ratio of solid inoculum has to be determined for each individual substrate. The necessary ratio of solid inoculum has to be taken into account in the dimensioning of farm scale plants.

Substrates with a good digestibility in „liquid-phase“ systems are not necessarily suitable for ìsolid-phaseî digestion in discontinuously operated installations. Material of a tight structure is not suitable for mono digestion and has definitely to be mixed with additional structure material. In our experiments green cut containing woody components and straw proved to be suitable as structure material.

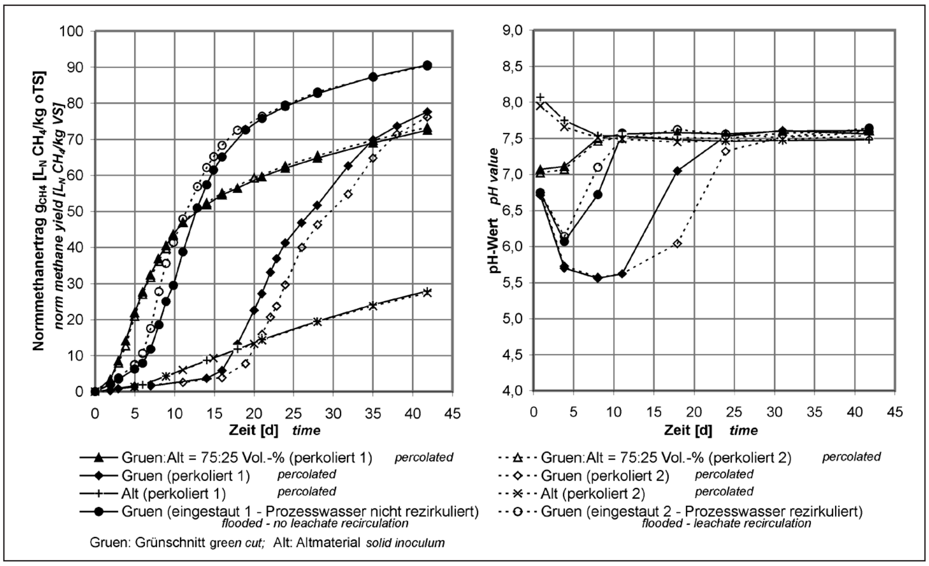

Fig. 2: Methane yields and pH values during digestion of green cut in different experimental set-ups with two parallels at laboratory-scale