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Lignocellulosic substrates – (not) a problem for biogas plants?

The sustainability of biogas production is determined by the price trend of the substrate, the development of new substrates, and the improvement of the energetic utilization ratio of the applied substrates. Till now, highly lignocellulosic substrates or residues like straw or landscaping material were considered as “not or limited usable for biogas production”. Reasons are the high lignin content, the distinct pith structure with cavities and layers of fat. The Fraunhofer IKTS in Dresden and LEHMANN Maschinenbau GmbH in Jocketa have examined the extent to which these difficult substrates are suited for the biogas production: It depends on the accurate digestion.

Keywords

LEHMANN, IKTS, Fraunhofer, Bioextrusion®, digestion, lignocellulose, straw, landscaping material, Miscanthus

Abstract

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Substrates such as straw, chaff, landscaping material and the like accumulate annually in large quantities, and are often plough back as humus forming. The fact is: decomposition of these biomasses extracts nutrients from the crops, particularly nitrogen [1]. This leads either to considerable crop losses or expensive additional nutrient. On the other hand, these lignocellulosic feedstocks could accomplish a quite positive contribution to a balanced nutrient ratio in the fermentation substrate of biogas plants. This applies especially in a common fermentation with albuminous substrates such as chicken manure, dry manure as well as meat and slaughterhouse wastes. The during the fermentation unreacted substances are available furthermore in the digestate as nutrients as well as humus forming. In addition, digestate has a higher availability for crops than unfermented substrates.

Pretreatment

The microorganisms must have an access to the cellulose and hemicellulose to improve the decomposition behavior of (ligneous) substrates. Therefore the protective lignin structures must be extensively broken (**Figure 1**) and it must to lay open the cellulose and hemicellulose structures (descaling).

This pretreatment is technically very efficiently through the use of bioextrusion® accessible, suitable for both new installations and retrofit alike. Thereby the substrate is expose between two reverse-rotating screws with rapidly changing loads of pressure and temperature peaks, whereas it is frayed, simultaneous plasticized and compacted. The frayed substrates are exposed to the metabolic activity of microorganisms in the downstream reactors (hydrolysis and/or digester). The produced enzymes will receive immediate access to the substrate, as a result it originates a measurable acceleration in the separation of cellulose and hemicellulose structures in quintuble and sextuble sugars, which lead in turn to increase in gas production rate and degree of degradation. The substrate does not float and distributes well in the tank.

Crop straw

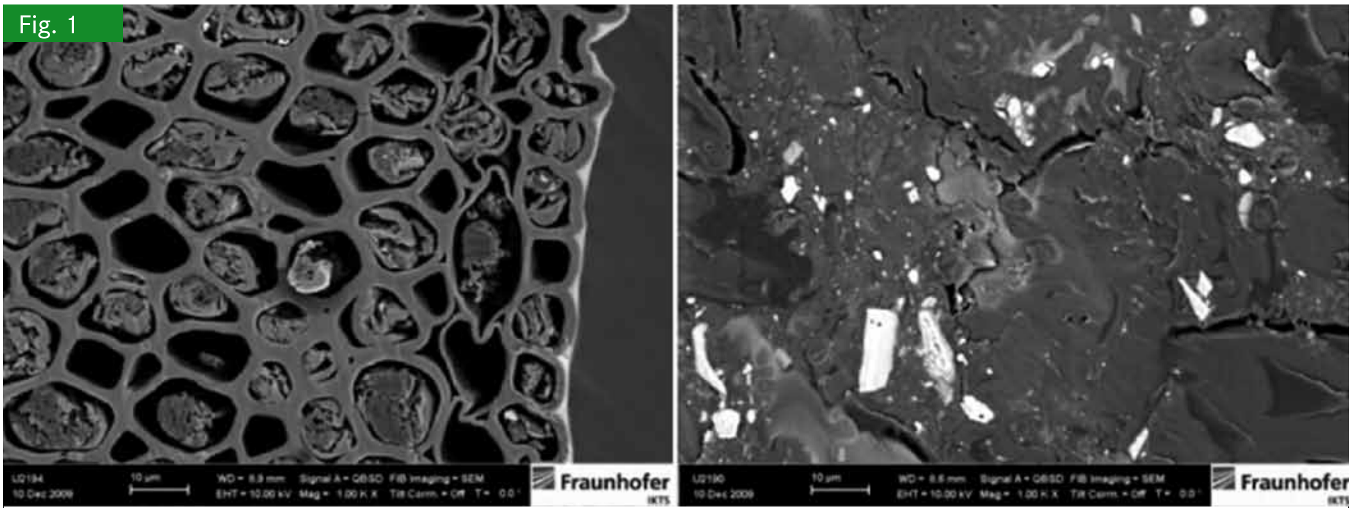
Crop straw has the highest potential of residues in Germany with 8 to 13 million t/a. The conflict between humus supply and removal of straw from the field by returning the digestate is here defused in contrast to thermal utilization. A full decomposition with chemicals, not common in practical systems until now, has been examined. Clearly visible was a high biogas yield with bioextrusion® (**Figure 2**).

However, the fermentation of straw or also large proportions of the substrate is hardly being practice because it leads without a prober pretreatment to several problems such as stirrability, floating behavior, gas exchange in the digester or nutrient supply. In the experiment, wheat straw was fermented at pilot scale for several months with 520 NL biogas/kg oTS_{zu} with bioextrusion®. This shows that the straw fermentation is an alternative for world-scale plants and is worthwhile by thermal mechanical digestion. Concepts to this are in the planning.

Hybrid rye

With hybrid rye, harvested and ensiled with 70 % dry matter content, it is possible gain up to 420 Nm³ CH_4/t organic dry matter. That means at least 6.000 m³ methane gas production/ha by 14,3 t dry matter. How is this to be evaluated in compari-

Fig. 1



Cut (finley chopped) substrate (left) and extruded substrate (right)

son to maize? 6.000 m³ methane/ha are specified by 60 tons of maize harvest. The Saxon harvest average limits 40 t/ha and the national average in 2010 limits at 40.3 t/ha. This should be more favorable in 2011. Hybrid rye as a winter fruit has good start conditions, because it utilizes the moisture in the winter and promises always a good harvest. The last three years it was in the Vogtland, in 400 m height and 35 base points, over 20 tons of crop yield/ha with a dry matter content of approx. 65 to 70 %. It surpassed even maize due to its high methane content. The silage had a high quality and fungal infections were not noted. The smell of silage was less intense than the other silages and this in spite of the high dry matter content. Measurements have confirmed that the strawy substrate with grain content exceeds the yield of maize or at least equivalent [2]. The cultivation of hybrid rye will help to improve the value of land (humus and nutrients supply) and to organize a good crop rotation.

Maize straw

Maize straw has a high potential, especially in the countries and areas where the grain of maize is harvested separately. Thereby the plant is not harvested green, because of its high starch content of the grain, it remains long on the stalk and is yellow. Dry matter content and lignin content are high.

So far the straw and also the spindle (part of the piston) are hardly used, but plowed to a great extent. After a pulping process, the substrate is proving to be very worthy of use, for the biogas plant as well as for animal food. The fermentation has reached on average 336.81 Nm³ CH_4/t organic DM. A combined pulping and compaction process of straw allows producing of pellets which can be transported economically over long distances. This means for biogas plants that the extrude /agglomerated substrates, which are stable and easily tradable, have only to be dissolved.

Miscanthus

For miscanthus, there are already several studies, e.g. of the Biogas Forum Bayern. Their conclusion: “A summer pruning in August to the end of the main growth period results in growth depression and in a massive loss of revenue in the following year and can not be recommended. Under the current state of knowledge miscanthus can not be used as a biogas

Fig. 2

Untreated (left), wet extruded (middle), and dry extruded straw (right) substrate culture [3].” But with the bioextrusion® miscanthus can be used a biogas substrate culture, as tests have shown. The substrate was harvested in March/April 2011. The yellow grass was very dry (DM 80 to 85 %) and relatively hard, it was chopped small, pulped with the Bioextruder and fermented according to VDI 4630. The use in biogas plants is also rewarding in regard to the substrate price. However, the availability of miscanthus in Germany is currently not sufficient. The possibility of using this plant as a substrate for biogas could promote the cultivation. Regarding the seizure of methane up to 365 Nm³ CH_4 /t organic DM could be achieved. This means with about 20 t of dry mass [4] at least 7,300 m³ CH_4/ha and so 1,300 m³ CH_4/ha more than with corn with a crop yield of 60 t/ha. The biogas productivity of untreated Miscanthus after 30 days is reached in the extruded sample already after about 10 days. Overall, a methane gas increase has been achieved by 114 % after 30 days by bioextrusion® compared to the untreated sample.

Manure

Extruded horse manure shows a 28 % higher specific methane production per kilogram of dry organic matter than the untreated horse manure. This is the result of a higher gas yield (33 %) per kilogram of fresh weight. The rate of methane production was especially during the first three days much higher than in the untreated sample. This indicates a large amount of low molecular weight, quickly available organic matter in the extruded horse manure. Similar or even better results are obtained with bioextrusion® with cattle manure. A high proportion of straw makes manure interesting as a substrate for biogas plants, since the straw increases the energy content per tonne of fresh weight. For years, biogas plants that use 70 to 90 % cattle manure operate with bioextrusion®.

With respect to the dry matter content, and substrate composition highly variable and heterogeneous substrates, the range of the extruder was extended. Thus, a water separation is effected during the pulping and by other types of worms the pulping increases by the friction of the “greasy” substrate. The patent-pending solution has been proven and is in demand.

Landscaping material

Landscaping material is a very undifferentiated and inhomogeneous material. It is currently rarely used energetic and is used in biogas plants only reluctantly, also in view of “landscape maintenance bonus”. The structure of the landscape material during delivery ranges from fresh, soft (grass-like) material up to the woody, hard substrate which is septic, in digestion or rotten. A balance is difficult because the energy levels vary widely. But this is an important criterion for biogas production, to utilize the systems well. Problems are contaminants, such as wood, stone, plastic waste, etc. Regarding this the bioextrusion® has proven its worth. Together with a feeding system and an impurity selection the substrate is send homogenized and pulped into the fermentation. The process is running in wet fermentation plants and is stable in the model and demonstration plant BioEnergy Poehl. Applied for a patent is the bioliquid process. It’s goal is to win an energy-rich liquid and a solid. The liquid is fed into the fermentation and the solids will be used as compactions after a drying process for the combustion or for another material use.

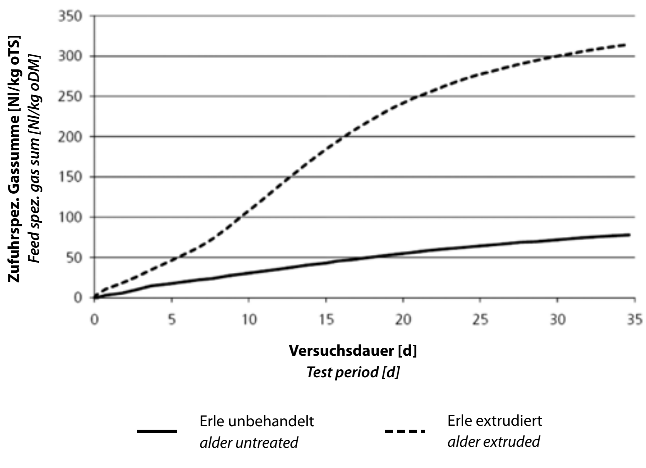
Rape Straw

To date rape straw is rarely used in biogas plants. It is, however, stored well in ensiled form (up to 70 % DM) or as straw (>70 % DM). Flashy are the different biogas yields, depending on the harvesting of rape grain and on the fact if the straw was sprayed before the harvest or naturally matured. The harvest is about 5–6 t /ha. If it is possible to recover the fine grain and the chaff (weed seeds, etc.), 8 to 9 t/ha are expected. After the bioextrusion® the rape straw can be used in biogas plants without problems and it produces good returns that justify the expense of harvesting, storage and thermo-mechanical pulping.

Woody bush and tree trimming

For landscape maintenance, especially during highway maintenance, a large amount of hedge cutting are produced. The use of this substrate in biogas plants seems, under the aspect of gas productivity investigation, with bioextrusion® quite possible. In **Figure 3**, the biogas productivity is applied on the example of alder with 320 Nm³/t organic dry matter. However, the fermentation without bioextrusion® is practically impossible. From the use of wood other benefits can be derived, however, these have to be investigated in future work: wood pulp as a carbon source and growth substrate for bacteria in biogas plants can also have a positive effect. The effect of different constituents, such as tannic acid, tannins, etc. is to investigate the biology of the fermenter. It is particularly important to recognize inhibitory effects and may determine the limits of fermentation.

Fig. 3



Fermentation curve thin hard wood (alder) according to the Association of German Engineers 4630

The deodorizing effect of wood fiber to odors, especially ammonia and hydrogen sulfide, is known. Is it possible for wood to achieve this in a biogas plant? Wood pulp is also a natural flocculants and improves the dewatering of sludges, even of fermentation residues. Regarding this researches are necessary to recommend formulations and meaningful amounts.

Conclusions

The substrate pretreatment brings energy benefits for the fermentation process. By shredding the viscosity of the substrates is reduced, which reduces the required energy for mixing. Furthermore, the reduction has a positive effect on the quality of mixing in the reactor and avoids partial sinking and floating layers [5]. Upon mixing of the coarse-chopped straw an average viscosity in the reactor of 2,260 mPa s (milli Pascal second) was determined, by the use of extruded straw it fell to 880 mPa s, the power input is reduced and the mixing quality can be improved. In reactors with a large diameter, such as in agricultural biogas plants, the well mixed reactor chamber is reduced by the use of ungrounded substrates to 60 to 70 %. By using the extrusion, an improvement of about 10 % can be reached. A particular advantage of bioextrusion® has to be emphasized: the avoiding of floating layers. They occur mainly in the use of fibrous substrates such as straw or grass silage and they often can not be stirred with a conventional mixing technology. After bioextrusion® and the associated size reduction as well as the change in the fiber structure, the problems of the floating layer formation do not exist.

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