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Straw instead of field crops

Around 30 million tonnes of cereal straw are produced in Germany annually, 8 to 13 million tonnes of this can be used sustainably for different energetic paths of utilization depending on the chosen evaluation method. Straw is one of the agricultural residues with the largest so far only partially occupied potential [1]. So far the energetic use of straw is based on the thermal recovery. The disadvantages of this are the extremely large storage capacity as well as the high CO_2 emissions from transport and processing. In contrast, the use of straw in anaerobic digestion seems sensible. The nutrients and organic matter, which was not converted into biogas in the fermentation process, are available again as a high quality digestate after fermentation for fertilization.

Keywords
Lehmann, IKTS, Fraunhofer, Bioextrusion®, digestion, lignocellulose, straw, landscaping material, miscanthus

Abstract
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The introduction of the Renewable Energy Sources Act (EEG) in 2000 and the amendments in 2004 and 2009 have led to a rapid development expansion of plants and equipment for production of biogas in Germany. The fact, that in recent years mainly readily degradable substrates with a relatively low portion of lignocelluloses was applied in biogas plants led in some German regions to an inflationary cultivation of maize and thereby to the well known criticism on the biogas sector. The amendment of the EEG in 2012 has led to the appeasement of this grievance and has intensified the production of agricultural residual materials like straw. At the moment, the legislative paves the way for the appliance of straw in biogas plants.

Straw has a very high content of lignocelluloses and a low portion of readily fermentable materials. During the fermentation process this causes very long digestion time and a low biogas yield. Straw has a floating character in the fermenter, even after being shredded. This tends to result in an increasing formation of unwanted floating layers. Hereby, the liberation of biogas during the process is massively hindered and the functionality of the overall process is significantly restricted. Furthermore, the energy input for the mixing of these fermentation materials is immense, so that the efficiency of such plants is significantly reduced.

To counteract to these substrate-specific disadvantages, the pretreatment method of Bioextrusion® was developed. On one hand, the treatment (extrusion) of the straw reduces the particle size (fiber length); then again it leads to the digestion of the lignocellulosic composites. Thereby, the lignocellulosic structure is partially destroyed and, at the same time, the water absorptive capacity of the straw increases.

Figure 1a and **1b** show a grid-electron microscope picture of nearly untreated and extruded wheat straw. The structural change as result of the Bioextrusion® is obvious.

This type of pretreatment reduces the floating behavior of straw fibers inside the fermenter. It is easier to stir the digestate and it spreads almost perfectly in the operating volume of the fermenter.

Substrate which is modified by Bioextrusion® favors a more effective biogas formation process in the wet-fermentation process.

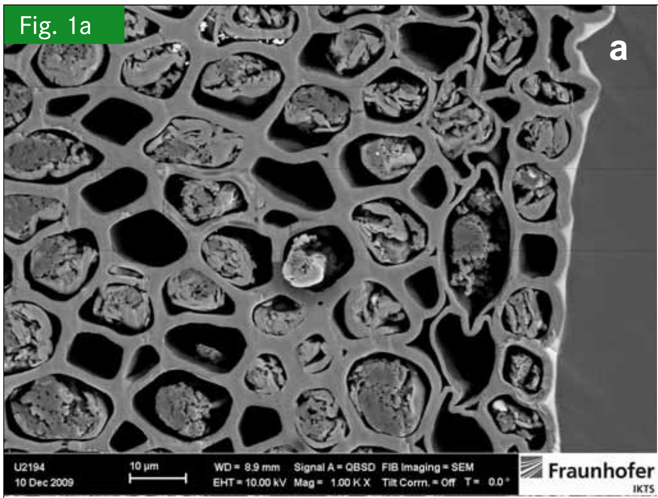
Process description

The hydrothermal disintegration significantly enlarges the specific surface of the straw, so that both the hydrolysis and the formation of biogas can be accelerated. The ongoing disintegration of the lignocellulosic structure partially abrogates the protective effect which the lignin has on degradable hemicelluloses and cellulose fractions. After the pretreatment with Bioextrusion® there is a larger amount of organic material available for the microorganism of the biogas process. This results, measured on the increase of the specific biogas yield during a field trial according to VDI 4630, in an increase of 21 % (**Figure 2**).

In continuously conducted field trials as pilot scale with extruded straw, it was conducted that there is a specific methane yield of 270 $I_N CH_4$/kgODM at an average volume load of 2.25 kgODM/$m^3{}_{OV}{}^d$ over a time period of 200 days.

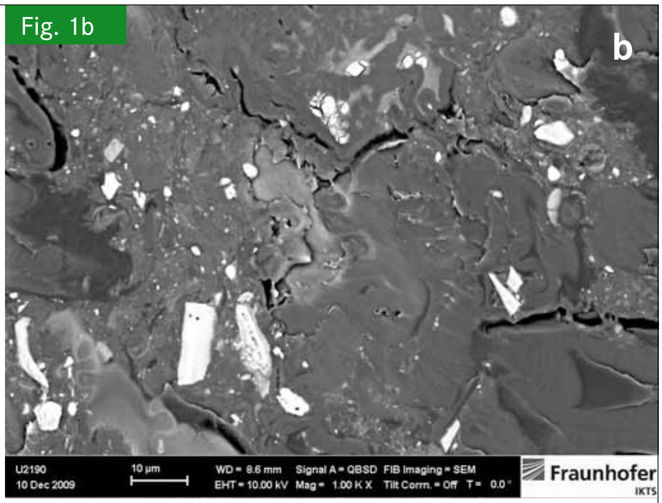
The disintegration of lignocellulosic substrates by Bioextrusion® opens new technical and economic attractive alternatives to the prior used renewable primary products in the biogas production [2]. The biogas yield of the substrates which are treated with the extrusion process equal does substrates pretreated with thermal pressure hydrolysis [3].

Fig. 1a



SEM-image untreated wheat straw, cut (finley chopped) substrate

Fig. 1b



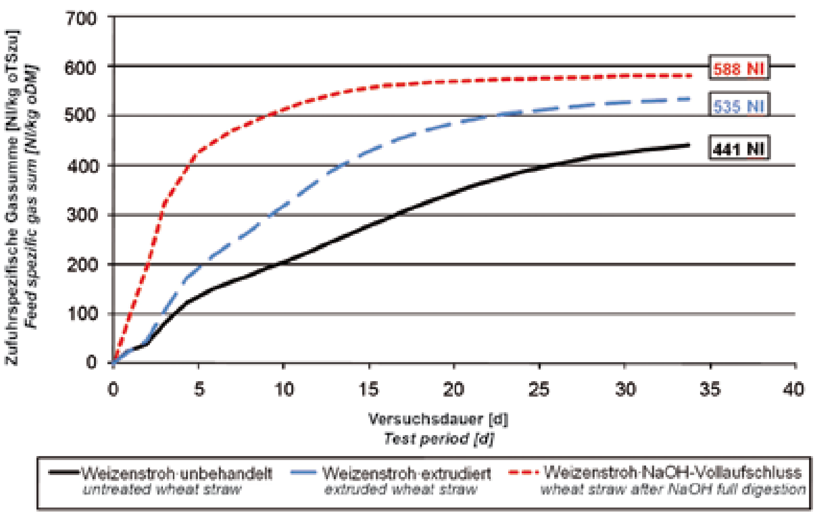
SEM-image of extruded wheat straw

Advantages of the straw monofermentation

Straw with a dry substrate content of 85 to 90 % is very light and voluminous and the energy input for the disintegration of the dry material is relatively high. The Bioextrusion® assures a considerable low energy input (kWh/t_{FM}) as for example mills which have to overcome the restraining effect of the fibers. Furthermore, there is no dust and therefore no potential for the development of explosions and fires. The continuously operating system of the bioextruder, which at the same time functions self-cleaning, is essential for a profitable operation of a straw monofermentation. The above mentioned advantages are supported and complemented by multi-step pretreatment and fermentation techniques of the company Lehmann Maschinenbau for which property right are register.

During the multi-step process, the first step is to dissolve and chop the straw bale. Alternative, it is possible to use chopped straw which is stored in a haystack. The shortened substrate with a length of approx. 4 cm is transported by a dosing feeder in a tempered upstream hydrolysis. Thereby, the upstream behavior of the straw is used. The fluid phase of the digestate or liquid manure is used for the alignment of the solid content. During the following upstream procedure, extraneous material like ashes, stones, metals are separated and discharged downward due to their weight. After a short dwell time, the straw is compacted on its way upward, hydrolyzed and dissolved. The swollen substrate, which is accelerated through the temperature control, softens and is transported by a mechanical discharging device to the self-contained bioextruder to be disintegrated. The energy consumption of the bioextruder reduces

Fig. 2



Batch fermentation curves according VDI 4630 of untreated and different treated wheat straw to around one third of the value of dry disintegration. The wear cost are below 0.60 €/t fresh mass. After the pretreatment, the substrate passes the general known stages of the fermentation. To accelerate the fermentation and to increase the yield, it is possible to complement the system with an acidification and/or adding enzymes.

The multi-stage pretreatment of the substrates can be installed as full or partial current version or for retrofitting of existing biogas plants. The method is also suitable for the monofermentation of substrate. The equipment can be delivered in various manufactured sizes. The digesters are manageably small because the gas formation accelerates with a shorter dwell time. A 500 kW_{el} biogas plant can be operated with wheat straw by a substrate input of approx. 12 t/d. The Bioextrusion® method is already applied on plants operating with 70 and 90 % cattle manure with a high straw content as well as on monofermentation plants operating with horse manure. The company-owned 499 kW pilot plant is operated with proportionately large amounts of rape straw (dry mass 65–90 %). The gas yield of rape silage is slightly below the biogas yields of maize silage.

Conclusions

Technically and economically, the Bioextrusion® provides all conditions for the monofermentation of straw. The method is also suitable for grass and landscaping materials in ensiled, fresh or mature form. A major advantage is the secured discharge of extraneous material. This protects the technology like the disintegration machine or pumps and in addition reduces the sedimentation inside the fermenter or digestate storage.

Maize straw is also suitable for the process and is already being successfully applied in fermentation. Multi-annual plants with high dry matter content offer a further potential. Mischanthus, which is harvested in spring, obtains a methane gas yield between 5 000 and 7 500 m^3/ha – the margin results from different sites and land values. Miscanthus monofermentation plants are a profitable way to use this interesting substrate sustainable in biogas plants. At the moment, there is an interesting mining technique for the use of wheat husk being developed with which concurrent wheat seeds can be removed and the subsequent costs for maintenance can be reduced. The range of usable substrates favors a good crop rotation and allows the use of landscaping material, roadside vegetation and previously unused substrates.

Literature

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