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Steam explosion pretreatment for enhancing biogas production of Alpine hay

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Abstract

Growing grassland biomass in an extensive way and its subsequent transformation into hay for a further utilization in a biogas-based biorefinery concept could be a solution to increase incomes and maintain the grassland area. In this way, grassland can be promising biomass sources for decentralized energy generation. Efficient biogas production from this lignocellulosic biomass requires a pretreatment step. One of the most efficient pretreatment methods for lignocellulosic materials is steam explosion. The main objective of this work was to evaluate the effect of temperature and time that steam explosion pretreatment has on the biogas production and physico-chemical characteristics of Alpine hay. Results from scanning electron microscopy (SEM) images of the pretreated biomass indicated that steam explosion induced significant morphological changes. Steam explosion increased the methane yield up to 276 l_N kg⁻¹ VS, representing a rise of 14 % when compared to untreated hay. The outcomes indicate that hay can be effectively converted to methane after steam explosion pretreatment and its utilization could be a key strategy to obtain economical incomes that allow maintaining grasslands in Alpine regions. However, further attempts in optimizing the pretreatment process should be made since the efficiency of the total process can be improved significantly.

Keywords: biogas, methane, hay, biofuel, steam explosion

1 Introduction

Grasslands, one of the largest habitat type in the world, has numerous functions and values regarding ecology, economy and society (Peeters, 2009). However, in the last decades, the grassland area has declined considerably. It is therefore of vital importance that alternative land use concepts are developed to help maintain Alpine grasslands. One possible strategy is the biogas-based biorefinery concept, which entails using grassland biomass to produce energy and chemical components.

The utilization of energy produced from renewable resources such as grasslands is an important factor to reduce fossil energy consumption. Processing technology and logistics for

the cultivation of grassland as well as its harvesting and storage are technically well-engineered processes and have been successfully used for decades. However, there is still a big necessity of R&D in the field of biogas processing technology..

The utilization of biomass from extensive grassland will help mitigate its current reduction, preserving unique structures and landscapes by providing a de-centralized energy production and additional value creation (Buchgraber, 2004). For efficient methane production from grass, a pretreatment step is necessary and can lead to an important economic gain (Thamsiriroj & Murphy, 2010). This step makes possible the optimization of the whole process regarding technical, economic and ecological aspects. Steam explosion is one of the most intensive investigated pretreatment technology of lignocellulosic material for both ethanol and biogas production and the required thermal energy can be obtained from the waste energy from the CHP, optimizing the efficiency of the whole process. The aim of this study was to evaluate the effect of temperature and time of steam explosion pretreatment on the biogas production of Alpine hay. Steam explosion was tested for a range of different temperature and time combinations. For every pretreatment, scanning electron microscopy (SEM) pictures were taken and methane yields were measured for a better understanding of the effect of the pre-treatment severity on the degradation process.

2 Material and methods

The hay used in the study was harvested in Purgstall an der Erlauf (Austria) in 2010. The biomass was dried on the field and the samples were stored in a sheltered place until the start of the tests. The material was chopped to a length of 10 to 15 cm before pretreatment process and it was pretreated with a steam explosion unit at the University of Life Sciences (UMB) in Ås, Norway. The steam explosion pretreatments were performed at temperatures ranging from 160 °C to 220 °C and each temperature was maintained for 15 min. The steam-exploded material was vacuum stored at 4 °C.

In order to document the disruptive effect of SE on the pretreated samples, scanning electron microscopy (SEM) was carried out at the Institute of Materials Science and Process Engineering (BOKU, Vienna). In a first step, samples were sputtered with a thin layer of gold to guarantee their electrical conductivity. A gold film of approximately 10 nm was grown using a Scancoat Six SEM (Edwards) sputter coater. Then, the scanning electron microscope "FEI Quanta FEG 250" was used with "X EDAX Apollo SDD" EDS and X-ray detectors. Molten zirconium served as a light source, which is focused by the ring magnets on the sample. Electrons are ejected and their subsequent detection enables the display of the surface of the sample.

The untreated and pretreated variants were analyzed regarding dry matter (DM) and volatile solids (VS) content. The DM was analyzed by drying the biomass in an oven at 105 °C until constant weight was reached. The raw ash (XA) was analyzed by determining the residue left after dry oxidation of the oven dried material in a muffle furnace at 550 °C (Sluiter et al., 2004). The VS were calculated from the XA content (Naumann & Bassler, 1993).

Anaerobic digestion batch trials were carried out in triplicate in accordance with VDI 4630 (VDI, 2006), employing eudiometer batch digesters of 0.25 l capacity. The substrates and the inoculum were weighed out in a ratio of 1:3 (based on volatile solids content). The inoculum utilized was taken from a biogas plant in Parndorf (Austria). The digesters, incubated at 37.5°C, were continuously stirred and the biogas yields were monitored on a daily basis during the whole digestion process. Biogas and methane production were measured in norm liters (273 K and 1013 mbar) per kg of volatile solids ($I_N \text{ kg}^{-1} \text{ VS}$). The portable gas analyzer Dräger X-AM 7000 was used to determine the biogas composition (CH_4 and CO_2).

3 Results and discussions

Scanning electron microscopic analyses of native and pretreated samples at different severities (160, and 190 °C for a retention time of 15 min) were carried out to assess alterations in the morphology. Fig. 1(a) shows the SEM micrograph of native hay. The changes in the morphology caused by steam explosion are already noticeable under the weakest pretreatment conditions as shown in Fig. 1(b). Here, the beginning of the separation of fibers begins to be sensed. An increment of the temperature up to 190 °C (Fig. 1(c)) showed structural changes in the biomass, which may be due to a solubilization of the cementing materials (mainly lignin and hemicellulose), inducing a remarkable defibrillation effect.

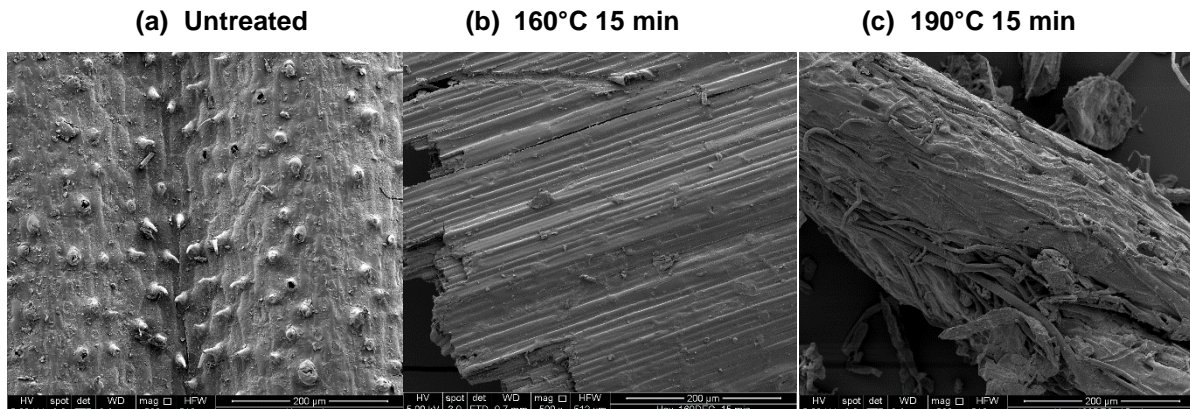


Figure 1. Scanning electron micrographs of untreated and steam-exploded hay under magnifications of 500x.

The methane yield of the native sample differed from the steam exploded samples. With a pretreatment temperature of 160 °C the specific methane production increases in comparison to the untreated sample. However, pretreatment temperatures higher than 175 °C decreased the methane production in comparison to the untreated sample. This can be caused by different processes occurred during the pretreatment step such as the production of inhibitors (e.g. furfural and hydroxymethylfurfural) and the formation of pseudolignin

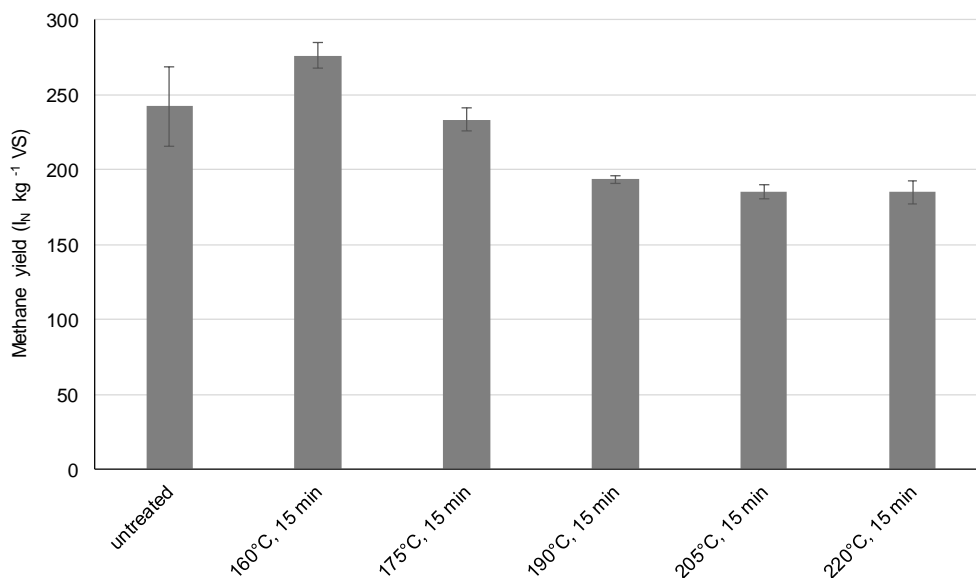


Figure 2. Methane yields of native and pretreated hay.

4 Conclusions

Results show a slight increase in the specific methane yield of hay after pretreatment with steam explosion. Pretreatment temperatures of 175 °C or higher led to lower methane yields, probable caused by the production of aromatic compounds. Hay needs milder pretreatment conditions to achieve a high degradation, in comparison to other biomass, which leads to lower energy requirements. The utilization of hay as a feedstock in biogas-based biorefinery concepts could help maintain grasslands in Alpine regions. Further attempts to optimize the pretreatment conditions should be undertaken.

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