Biogas Production from Lignocelluloses: Pretreatment, Substrate Characterization, Co-digestion and Economic Evaluation

ANNA TEGHAMMAR

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Fakultetsopponent är professor Chettiyappan Visvanathan, Asian Institute of Technology, Bangkok, Thailand.

Institutionen för kemi- och bioteknik
CHALMERS TEKNISKA HÖGSKOLA
412 96 Göteborg
Telefon 031-772 1000

Ingenjörshögskolan
HÖGSKOLAN I BORÅS
501 90 Borås
Telefon 033-435 4000
Abstract

Biogas production from organic materials can be used as a renewable vehicle fuel, provide heat and generate electricity and can thereby reduce the greenhouse gas emissions. This thesis focuses on the biogas production based on lignocelluloses. There is an abundant availability of lignocelluloses, constituting 50% of the total biomass worldwide. However, the biomass recalcitrance limits the microbial degradation as well as the biogas production from these types of materials.

In the present work different pretreatment methods have been performed in order to decrease the biomass recalcitrance and improve the biogas production. Steam explosion pretreatment, together with the addition of sodium hydroxide and hydrogen peroxide, has been performed on lignocellulosic-rich paper tube residuals. The pretreatment has resulted in methane yields of up to 493 NmL/gVS, which is an increase by 107% compared with untreated material. Furthermore, the use of an organic solvent, N-methylmorpholine-N-oxide (NMMO), was evaluated as a pretreatment method for spruce (both chips and milled), rice straw, and triticale straw. The NMMO pretreatment resulted in 202, 395, 328, and 362 NmL CH₄/g carbohydrates produced of these substrates, respectively, corresponding to an increase of between 400-1,200% compared with the untreated version of the same material.

Moreover, the paper tube residuals have been co-digested with an unstable nitrogen-rich substrate mixture, mainly based on municipal solid waste. The addition of the lignocellulosic-rich paper tubes in a co-digestion process showed stabilizing effects and prevented the accumulation of volatile fatty acids with a subsequent reactor failure. Additionally, synergistic effects have been found leading to between 15-33% higher methane yields when paper tubes were added to the co-digestion process compared with the yields calculated from the methane potentials of the two substrates.

Substrate characterization analysis can be used to study the changes on the lignocellulosic components after the pretreatment, relating the changes to the performance in the anaerobic digestion. Increased accessible surface area, measured by the Simons’ stain and the enzymatic adsorption methods, as well as decreased crystallinity, determined by using the Fourier Transform Infrared Spectroscopy, can all be linked to improved biogas production after pretreatment.

Finally, the NMMO pretreatment on forest residues has been financially evaluated for an industrial scale process design. The base case that was evaluated simulated a case where pretreated forest residues were co-digested with the organic fraction of municipal solid waste to obtain optimal nutritional balance for the anaerobic digestion. This process has been found to be economically feasible with an internal rate of return of 20.7%.

Keywords: anaerobic digestion, biogas, lignocellulose, pretreatment, co-digestion, substrate characterization, economic evaluation.