Using hydrothermal pretreatment to enhance gaseous biofuels from forestry residues

M. Alexandropoulou[1], K. Papadopoulou[2], G. Antonopoulou[1,2,3,*], G. Lyberatos[1,2]

[1]Institute of Chemical Engineering Sciences, Stadiou 1, Platani, Patras, GR 26504, Greece
[2]School of Chemical Engineering, National Technical University of Athens, GR 15780 Athens, Greece
[3]Department of Sustainable Agriculture, University of Patras, 2 Georgiou Seferi str., GR 30100, Agrinio, Greece.
Keywords: willow sawdust, hydrothermal pretreatment, biogas, hydrogen, exploitation
Presenting author email: geogant@chemeng.upatras.gr

Abstract

In the present study, the effect of hydrothermal pretreatment (HP), on the production of hydrogen, through dark fermentation and methane, through anaerobic digestion, from willow sawdust (WS), was investigated. Four different temperatures (130, 180, 215 and 230°C) were evaluated for 15 min, during HP, to enhance WS solubilization, as well as hydrogen and methane generation through batch fermentative hydrogen production (FHP) and biochemical methane potential (BMP) tests, respectively. Results showed that both bioprocesses were enhanced due to pretreatment, which implying that HP is a proper treatment method for forestry residues, such as WS.

Introduction

Lignocellulosic biomass including forestry residues such as willow sawdust (WS) could be used as feedstock for anaerobic digestion (AD) and fermentative hydrogen production (FHP). Hydrolysis has been shown to be the rate-limiting step in the case of AD and FHP of such substrates. Although being abundant, since the annual world production of biomass residues exceed 220 billion tons, the main obstacles of their use are the low yields attained, due to the recalcitrant nature of their lignocellulosic content. The application of a pretreatment process prior to AD and FHP could improve the hydrolysis and the total methane and hydrogen yield.

Materials and Methods

Pretreatment

WS was chopped, milled, sieved to a powder and air-dried at ambient temperature. For all pretreatment methods used, the solids loading, expressed as total solids (TS), was 5% w/v, (5 g of TS in 100 mL water). Microwave digestion equipment (speedwave MWS-2, Berghof, Germany) with an IR sensor for temperature monitoring, was used for HP pretreatment. WS was pretreated at 130, 180, 215 and 230°C for 15 min. After pretreatment, the whole pretreated biomass was separated through vacuum filtration (0.7 μm pore size) and two fractions (a liquid and a solid one) were obtained. A detailed physicochemical and structural characterization was performed on both fractions based on Antonopoulou et al. (2015). Both fractions were used for the production of (a) hydrogen, through FHP and (b) methane, through BMP tests.

FHP and BMP tests

BMP experiments at 35°C were carried out in both separated fractions (liquid and solid fraction) obtained after HP, based on Antonopoulou et al. (2020). Briefly, in all experiments, 20 % v/v of anaerobic sludge was used as inoculum in serum bottles of 160 mL, with a working volume of 100 mL. Regarding experiments with the solid fractions obtained after HP, a final loading of 2g VS / L was used, while in the experiments with the liquid ones the final chemical oxygen demand (COD) concentration was 2 g/L.

FHP tests at 35°C were performed in the rich in cellulose, solid fractions of the pretreated biomasses, using commercial cellulase at a loading of 40 FPU /gTS (Celluclast 1.5L) and glycosidase (Novozyme 188) at a ratio of 3:1 (v/v), at simultaneous saccharification and fermentation (SSF) concept, as described in Antonopoulou (2020). Briefly, 20 % v/v of anaerobic sludge initially boiled at 100 °C for 15 min, was used as inoculum in batch serum bottles of 160 mL, with a working volume of 50 mL. HP pretreated solids at a final loading of 10g TS / L were used along with a basal nutrient medium, properly diluted (Antonopoulou, 2020). In the experiments with the liquid fractions, 20 % v/v of anaerobic sludge, properly treated was used along with 80 % of the hydrolysate, supplemented with the nutrient medium.

Results and discussion

The composition of the WS used in the present study was: volatile solids (VS): 94.1 ± 1.2 g/100gTS, cellulose: 33.4 ± 1.1 g/100gTS, hemicellulose: 21.5 ± 0.9 g/100gTS, lignin: 29.1 ± 0.6 g/100gTS, ash: 5.9 ± 1.6 g/100gTS, extractives: 3.0 ± 0.1 % g/gTS. Figure 1 summarizes the effect of pretreatment on the fractionation of biomass in terms of lignin, cellulose and hemicellulose (1a) and on the production of other substances such as formic acid, acetic acid, furfural and hydroxyl-methyl-furfural (HMF), which are referred as possible inhibitors in subsequent bioprocesses (Antonopoulou et al., 2015; 2016).

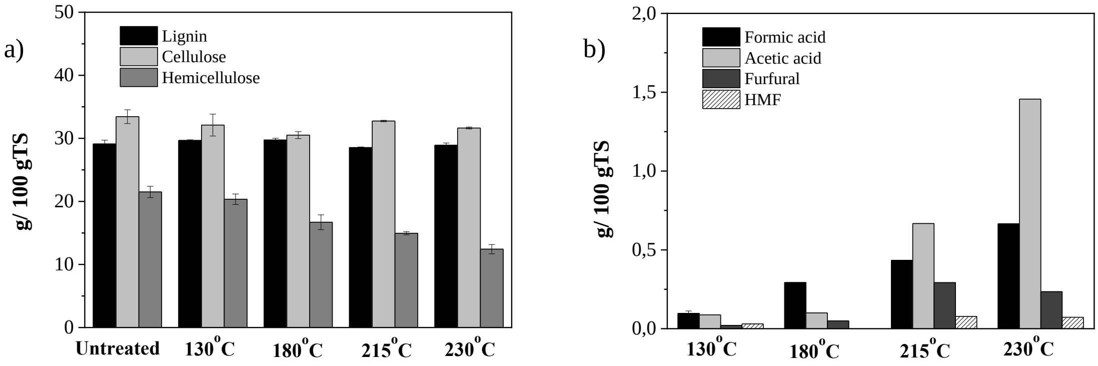

Figure 1. The lignocellulosic content (a) and substances such as formic acid, acetic acid, furfural and hydroxyl-methyl-furfural (HMF) (b) in g/100 gTS $_{initial}$ of the untreated and hydrothermally pretreated WS (130, 180, 215 and 230°C).

Effect of pretreatment on anaerobic bioprocesses

From Figure 2, where the effect of HP on the BMP (Fig.2a) and FHP (Fig.2b) of WS are presented, it is obvious that HP enhances the methane and hydrogen yields, especially at the higher temperatures of 215 and 230 °C, where the sum of biofuels from liquid and solid fractions, is higher than that of the untreated WS.

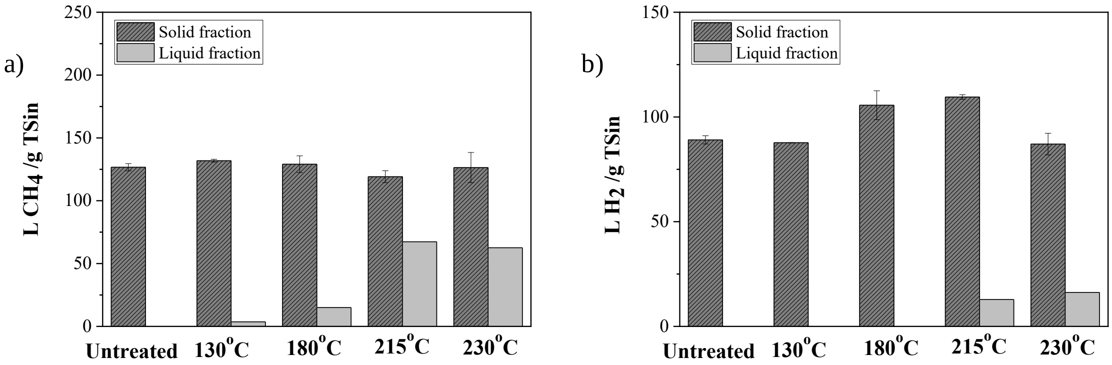

Figure 2. BMP (a) and FHP (b) of untreated WS as well as of the solid and liquid fractions obtained after HP of WS (130, 180, 215 and 230°C), expressed in L / kg TS $_{initial}$.

References

- Antonopoulou, G., Dimitrellos, G., Soto Beobide, A., Vayenas, D., Lyberatos, G. (2015) Chemical pretreatment of straw biomass: the effect on chemical composition and structural changes, Waste Biomass Valor. J. 6 (5) (2015) 733-746.
- Antonopoulou, G., Vayenas, D and Lyberatos, G. (2016) Ethanol and hydrogen production from sunflower straw: The effect of pretreatment on the whole slurry fermentation. Biochem. Eng. J.116: 65-74
- Antonopoulou, G., Vayenas, D and Lyberatos, G. (2020) Biogas production from physicochemically pretreated grass lawn waste: comparison of different process schemes. Molecules,25, 296
- Antonopoulou, G. (2020) Designing efficient processes for sustainable bioethanol and bio-hydrogen production from grass lawn waste. Molecules 25, 2889. https://doi.10.3390/molecules25122889