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Fractionation of wheat straw by prehydrolysis, organosolv delignification and enzymatic hydrolysis for production of sugars and lignin

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ABSTRACT

Wheat straw was fractionated using a three-step biorefining approach: (1) aqueous pretreatment for hemicellulose prehydrolysis into sugars, (2) organosolv delignification, and (3) enzymatic cellulose hydrolysis into glucose. Prehydrolysis was applied to avoid degradation of hemicellulose sugars during organosolv delignification. Maximum xylose yield obtained was 67% or 0.17 kg/kg straw (prehydrolysis: 175 °C, 30 min, 20 mM H_2SO_4) compared to 4% in case of organosolv without prehydrolysis (organosolv: 200 °C, 60 min, 60% w/w aqueous ethanol). Prehydrolysis was found to reduce the lignin yield by organosolv delignification due to the formation of 'pseudo-lignin' and lignin recondensation during prehydrolysis. This reduction could partly be compensated by increasing the temperature of the organosolv delignification step. Prehydrolysis substantially improved the enzymatic cellulose digestibility from 49% after organosolv without prehydrolysis to 80% (20 FPU/g substrate). Increasing the organosolv delignification temperature to 220 °C resulted in a maximum enzymatic glucose yield of 93% or 0.36 kg/kg straw.

1. Introduction

Biorefining is the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, and chemicals) and energy (fuels, power, and heat) (definition International Energy Agency, Bioenergy Task 42). Lignocellulosic biomass is a versatile renewable feedstock for biorefining, of which the main constituents are the biopolymers cellulose, hemicellulose, and lignin. Efficient fractionation of lignocellulosic biomass into its main constituents, such that all fractions can be valorized, is a prerequisite for an economic lignocellulosic biorefinery. In particular, the use of lignocellulosic agricultural and forestry residues for biorefineries seems promising because of high availability, relatively low costs and no direct competition with food and feed production. An agricultural residue that is often considered as a feedstock for biorefining is wheat straw (Talebnia et al., 2010). Wheat straw has also been chosen as feedstock for the work reported here.

Different lignocellulosic biorefinery concepts exist (Kamm et al., 2006). Within the so-called sugar platform, the cellulose fraction is first hydrolyzed into glucose, which can then be converted into e.g. bioethanol by fermentation. In case of enzymatic cellulose hydrolysis, direct hydrolysis of lignocellulose is very inefficient and pretreatment is required to render the cellulose fibrils more accessible to enzymes (Hendriks and Zeeman, 2009; Wyman et al., 2005). The aims of the pretreatment step include delignification, hemicellulose removal and reduction of the degree of polymerization and crystallinity of the cellulose fraction (Mosier et al., 2005; Taherzadeh and Karimi, 2008).

Organosolv is a pretreatment technology which has been reported to produce readily hydrolysable cellulose substrates in addition to lignin (Pan et al., 2005a; Zhao et al., 2009). The coproduction of a high-purity lignin stream is a major advantage of organosolv compared to other pretreatment routes like steam explosion and mild acid pretreatment. Lignin is a potential renewable source for aromatic chemicals, like phenolics, and performance products, like resins (Zakzeski et al., 2010). Vice versa, valorization of co-products (lignin as well as hemicellulose derivatives) is essential for an economic organosolv process (Pan et al., 2005a).

Hemicellulose is the most reactive of the three major structural constituents of lignocellulosic biomass. In this study, the aim is to convert wheat straw hemicellulose into sugars. A drawback of the organosolv process is that the conditions required to delignify lignocellulosic feedstocks may lead to low yields of hemicellulose sugars due to degradation and subsequent formation of humins and condensation products with lignin (Huijgen et al., 2010; Zhao et al., 2009). In earlier work on autocatalytic acetone-based organosolv pretreatment of wheat straw, we reported that, at conditions yielding maximum enzymatic digestibility (205 °C), the yield of the major hemicellulose sugar xylose was only ~4% of its theoretical maximum or 1% w/w raw wheat straw (Huijgen et al., 2010). The yield of furfural was only slightly higher.

A possible approach to avoid degradation reactions of hemicellulose sugars is prehydrolysis of the hemicellulose fraction into

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