Hydrolysis of organosolv wheat pulp in formic acid at high temperature for glucose production

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Abstract

Organosolv methods can be used to delignify lignocellulosic crop residues for pulp production or to pretreat them prior to enzymatic hydrolysis for bioethanol production. In this study, organic solvent was used as an acidic hydrolysis catalyst to produce glucose. Hydrolysis experiments were carried out in 5–20% formic acid at 180–220 °C. Wheat straw pulp delignified with a formicdel™ method was used as a raw material. It was found that glucose yields from pulp are significantly higher than yields from microcrystalline cellulose, a model component for cellulose hydrolysis. The results indicate that cellulose hydrolysis of real fibers takes place more selectively to glucose than hydrolysis of microcrystalline cellulose particles does. The effect of the particle size on pulp hydrolysis was investigated, the crystallinity of hydrolyzed pulp was measured by XRD analysis, and the product distribution and its influence on the process was discussed.

1. Introduction

Lignocellulosic crop residues are potential raw materials for production of chemicals, fuels and energy: they do not compete with food production, they are available abundantly and they are inexpensive. Currently, 10% of global primary energy consumption is supplied from biomass, which is mainly used by burning (Bauen et al., 2009). It is estimated that 1.5 Pg of agricultural residues such as corn stover, rice straw and bagasse is available globally (Kim and Dale, 2004). Wheat straw is the third largest lignocellulosic biomass available worldwide with an annual potential of 354 million metric tons (Kim and Dale, 2004); in the EU, wheat is the cereal crop with the highest production (Kootstra et al., 2009a).

Studies of the utilization of wheat straw cover for example the production of pulp (Jiménez et al., 1998; Kham et al., 2005), levulinic acid (Chang et al., 2007, 2009) or bioethanol (Talebnia et al., 2011). Pulping of agricultural residues can be carried out with organosolv methods. Organosolv methods use organic solvents like carboxylic acids or alcohols as cooking chemicals (Aantila, 2001). Pulping of the agricultural residues with organosolv methods has some superior features over conventional pulping methods. Firstly, silica remains mainly in the pulp, yielding black liquor that can be easily treated (Lam et al., 2001). Secondly, with organosolv methods it is possible to fractionate the raw material into pure streams of hemicellulosic sugars, cellulose fibers (pulp), and sulfur-free lignin (Sidiras and Koukios, 2004).

Levulinic acid, a versatile platform chemical of the future, is produced from C6 sugars of biomass with acid at elevated temperature (Shen and Wyman, 2012). Acids are also exploited in a pretreatment phase of bioethanol production. Lignocellulosic raw materials like wheat straw have to be pretreated prior to the enzymatic hydrolysis of cellulose to glucose and the fermentation of glucose to ethanol. Although dilute acid hydrolysis is a promising, cost-effective pretreatment option (Mosier et al., 2005) and probably even one of the methods most studied, there is a limited amount of literature available about dilute acid pretreatment of wheat straw (Saha et al., 2005; Guragain et al., 2011; Marcotullio et al., 2011). Dilute acid pretreatment is commonly carried out with strong mineral acids like sulfuric acid. On the other hand, carboxylic acids and other organic solvents have been studied lately for pretreatment of various agricultural raw materials (Kootstra et al., 2009b; Sindhu et al., 2010; Vanderghem et al., 2012; Zhao et al., 2009). For example, Sindhu et al. (2010) studied formic acid pretreatment under conditions of 60% (v/v) HCOOH and 120 °C in the presence of an H2SO4 catalyst. Kootstra et al. (2009a) optimized a pretreatment process of wheat straw for dilute maleic acid using a monetary measure.

The advantages of the organosolv methods are the easy separation and recovery of the solvent by thermal operations, environment-friendly treatment of effluents, and the production of sulfur and chlorine free lignin. However, some of the advantages are lost in several organic solvent-based pretreatment methods due to the addition of a mineral acid catalyst like HCl or H2SO4. In addition,