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Pilot-scale study on the acid-catalyzed steam explosion of rice straw using a continuous pretreatment system

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HIGHLIGHTS

- A pilot-scale continuous pretreatment system was successfully developed.
- The pretreatment system shows good operational stability and durability.
- 73% of the total saccharification yield was obtained.
- The system can be used for the production of bioethanol and bio-based chemicals.
- The total sugar yield of rice straw in different scale system was compared.

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ABSTRACT

A continuous acid-catalyzed steam explosion pretreatment process and system to produce cellulosic ethanol was developed at the pilot-scale. The effects of the following parameters on the pretreatment efficiency of rice straw feedstocks were investigated: the acid concentration, the reaction temperature, the residence time, the feedstock size, the explosion pressure and the screw speed. The optimal presteaming horizontal reactor conditions for the pretreatment process are as follows: 1.7 rpm and 100–110 °C with an acid concentration of 1.3% (w/w). An acid-catalyzed steam explosion is then performed in the vertical reactor at 185 °C for 2 min. Approximately 73% of the total saccharification yield was obtained after the rice straw was pretreated under optimal conditions and subsequent enzymatic hydrolysis at a combined severity factor of 0.4–0.7. Moreover, good long-term stability and durability of the pretreatment system under continuous operation was observed.

1. Introduction

Lignocellulosic materials, such as agricultural, hardwood and softwood residues, are potentially viable sources of sugars for the production of bioethanol, biobutanol, other biofuels or various valuable chemicals. Lignocellulosic materials are particularly attractive because they do not compete with food crops. In biomass processing, the primary goal is to remove the hemicelluloses and destroy the structure of the biomass so that cellulose is more accessible to enzymatic hydrolysis. This process is generally referred to as pretreatment, and it is one of the most difficult processes to optimize. Therefore, pretreatment is a central part of the lignocellulose-to-ethanol process.

Various pretreatment strategies have been examined, including dilute-acid hydrolysis, steam explosion, liquid hot water extraction, alkaline hydrolysis, ammonia treatment and various biological processes. Among these various types of pretreatment, dilute-acid hydrolysis and steam explosion has been widely tested in pilot scale equipment and is considered to more favorable method for industrial applications (Wyman et al., 2005; Alvira et al., 2010; Chandel et al., 2011; Modenbach and Nokes, 2012; Larsen et al., 2012). Moreover, addition of a mineral acid results in more efficient hemicelluloses hydrolysis and the subsequent enzymatic digestion during steam pretreatment. Therefore, the acid-catalyzed steam explosion process is considered to be close to commercialization (Galbe and Zacchi, 2012).

An estimated 600–900 million tons of rice straw are produced globally every year. Moreover, developing countries in Asia produce 90% of the world's rice straw (Sarkar et al., 2012). Therefore, rice straw is an attractive lignocellulosic material for biofuels and other useful biomass chemicals. Nevertheless, various characteristics of rice straw make it intractable. For example, rice straw is soft,

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