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Integrated bioethanol production to boost low-concentrated cellulosic ethanol without sacrificing ethanol yield

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ABSTRACT

Four integrated designs were proposed to boost cellulosic ethanol titer and yield. Results indicated co-fermentation of corn flour with hydrolysate liquor from saccharified corn stover was the best integration scheme and able to boost ethanol titers from 19.9 to 123.2 g/L with biomass loading of 8% and from 36.8 to 130.2 g/L with biomass loadings of 16%, respectively, while meeting the minimal ethanol distillation requirement of 40 g/L and achieving high ethanol yields of above 90%. These results indicated integration of first and second generation ethanol production could significantly accelerate the commercialization of cellulosic biofuel production. Co-fermentation of starchy substrate with hydrolysate liquor from saccharified biomass is able to significantly enhance ethanol concentration to reduce energy cost for distillation without sacrificing ethanol yields. This novel method could be extended to any pretreatment of biomass from low to high pH pretreatment as demonstrated in this study.

1. Introduction

Limited crude oil reserves and environmental concerns to mitigate greenhouse gas emissions have driven global research to explore alternatives to fossil fuels and renewable energy (Ragauskas et al., 2006). Bioethanol is one of the solutions and has been used to fuel vehicles, which could reduce our reliance on fossil fuels, meanwhile reducing the net greenhouse gas emissions (Limayem and Ricke, 2012). First generation ethanol production from starchy grain and sugar-rich crops has been commercialized at large scales while second generation cellulosic ethanol production has not yet been fully commercialized (Nigam and Singh, 2011).

Lignocellulosic plant is the most abundant and renewable biomass with substantial worldwide production, including agricultural residues such as corn stover and wheat straw, forestry wastes such as wood chips, dedicated energy crops such as switchgrass, and organic municipal solid waste, which makes it an indispensable feedstock for the production of commercialized biofuels and renewable chemicals (Gupta and Verma, 2015; Sun et al., 2016).

The majority of current global ethanol production is derived from starch-based crops (e.g. corn, wheat, and sorghum) or sucrose-rich materials (e.g. sugarcane, sugar beet) as they can be efficiently hydrolyzed to fermentable sugars, and directly used for fermentation (Erdei et al., 2010; Nigam and Singh, 2011). However, cellulosic ethanol production is not economically viable, and it is limited by biomass recalcitrance due to the complex intertwined structure of cellulose, hemicellulose and lignin which inhibits enzyme accessibility (Nguyen et al., 2016; Zhang et al., 2016a). A key challenge for cellulosic ethanol commercialization is the low ethanol titer and low fermentation efficiency (Erdei et al., 2010; Xu et al., 2016). Achieving high cellulosic ethanol titers and ethanol yields is still under development.

Through the biological conversion pathway, pretreatment, enzymatic hydrolysis and fermentation are the three major steps for ethanol production from lignocellulosic biomass (Zhang et al., 2016a, 2016b). To effectively convert lignocellulosic biomass into biofuels, pretreatment is usually required to break the lignin seal, disrupt the crystalline structure of cellulose and to increase surface area of the cellulose, rendering the polysaccharides more susceptible to enzyme hydrolysis (Jin et al., 2016; Mosier et al., 2005). Raw lignocellulosic biomass like agricultural residues usually contains 25–35% cellulose, 20–30% hemicellulose and 25–35% lignin (Xu et al., 2011), in which hemicellulose is relatively easy to decompose upon subjection to heat or acidic conditions, while cellulose and lignin are more resistant to thermal decomposition (Ko et al., 2015; Mosier et al., 2005; Yu et al., 2010). Various pretreatment methods, including dilute acid pretreatment, hydrothermal pretreatment and alkaline pretreatment, were

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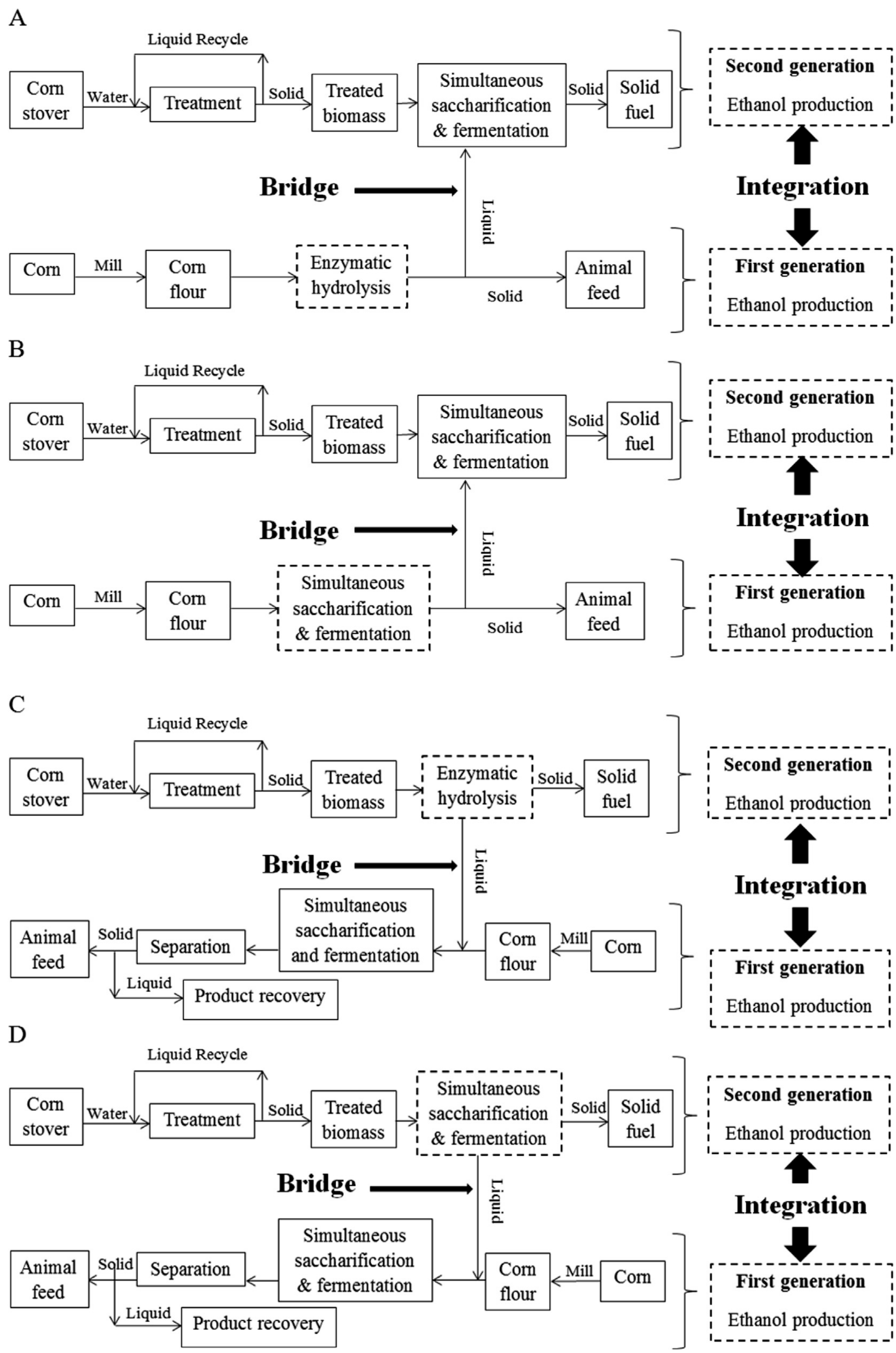

Fig. 1. Flow charts of integrated design.

studied to improve the enzymatic saccharification efficiency of lignocellulosic biomass (Mosier et al., 2005). Dilute acid and hydrothermal pretreatments are well developed and applied to improve enzymatic digestibility of cellulose by eliminating most hemicellulose linked with cellulose (Mosier et al., 2005). Consequently, the cellulose content of treated biomass could be greatly increased to approximately 50–60% and be highly exposed to enzymes (Yu et al., 2010). Hydrothermal pretreatment is an effective method to disrupt the microstructure of biomass and is considered as an environmentally-friendly process because it requires less waste disposal and less post-treatment