



Case Study

Maximizing cellulosic ethanol potentials by minimizing wastewater generation and energy consumption: Competing with corn ethanol



Gang Liu, Jie Bao*

State Key Laboratory of Bioreactor Engineering, East China University of Science and Technology, 130 Meilong Road, Shanghai 200237, China

GRAPHICAL ABSTRACT

Corn Ethanol vs. Cellulosic Ethanol

	Dry Mill	DryPB	DAP	AFEX	DMR	SE
Ethanol titer (% v/v)	-12%	10.8%	6.8%	5.1%	10.9%	7.7%
Cellulase usage (mg protein/g cellulose)	/	10 mg	20 mg	30 mg	20 mg	25 mg
Wastewater generation (per ton ethanol)	8.332 ton	8.768 ton	16.584 ton	20.712 ton	115.216 ton	115.741 ton
Electricity consumption (per ton ethanol)	34.5 kWh	262.9 kWh	324.6 kWh	529.2 kWh	1028.6 kWh	168.2 kWh
Steam consumption (per ton ethanol)	7.83 GJ	8.63 GJ	11.21 GJ	23.04 GJ	18.60 GJ	11.26 GJ
MESP (per gal ethanol)	~\$2.00	\$1.79	\$2.15	\$3.00	\$2.56	\$3.10

ARTICLE INFO

Keywords:

Cellulosic ethanol
 Dry acid pretreatment and biodegradation (DryPB)
 Wastewater generation
 Energy consumption
 Minimum ethanol selling price (MESP)

ABSTRACT

Energy consumption and wastewater generation in cellulosic ethanol production are among the determinant factors on overall cost and technology penetration into fuel ethanol industry. This study analyzed the energy consumption and wastewater generation by the new biorefining process technology, dry acid pretreatment and biodegradation (DryPB), as well as by the current mainstream technologies. DryPB minimizes the steam consumption to 8.63 GJ and wastewater generation to 7.71 tons in the core steps of biorefining process for production of one metric ton of ethanol, close to 7.83 GJ and 8.33 tons in corn ethanol production, respectively. The relatively higher electricity consumption is compensated by large electricity surplus from lignin residue combustion. The minimum ethanol selling price (MESP) by DryPB is below \$2/gal and falls into the range of corn ethanol production cost. The work indicates that the technical and economical gap between cellulosic ethanol and corn ethanol has been almost filled up.

1. Introduction

Sugar platform pathway of lignocellulose biorefining for cellulosic ethanol production includes the steps of prehandling, pretreatment, detoxification (conditioning), hydrolysis, fermentation, and recovery (Lynd et al., 2008). Currently, the biorefining technology is still on the early stage of commercialization with only limited number of commercial scale plants in practical operation (Balan et al., 2013). The concept of minimum ethanol selling price (MESP) is frequently used to quantitatively describe the overall cost of biorefining process starting from the feedstock coming at the factory gate and ending by ethanol product leaving the plant (Aden et al., 2002; Humbird et al., 2011). The

MESP values of several mainstream biorefining processing technologies (indicated by their pretreatment methods) are \$2.15 per gallon by dilute acid (DAP) (Humbird et al., 2010, 2011), \$3.00 per gallon by ammonia fiber explosion (AFEX) (Uppugundla et al., 2014; Kim and Dale, 2015), \$2.56 per gal for deacetylation and mechanical refining (DMR) (Chen et al., 2015, 2016), and \$3.10 per gal for steam explosion (Chen and Fu, 2016) based on the *n*-th plant assumption with all the required processing technologies at the mature stage. The overall cost of each technology is obviously greater than the current corn ethanol selling price (\$2/gal, the average value in the period of 2012–2017, <http://www.tradingeconomics.com/commodity/ethanol>). Reduction of the overall cost on cellulosic ethanol production to the profitable level

* Corresponding author.
 E-mail address: jbao@ecust.edu.cn (J. Bao).

<http://dx.doi.org/10.1016/j.biortech.2017.08.070>

Received 7 July 2017; Received in revised form 11 August 2017; Accepted 12 August 2017

Available online 21 August 2017

0960-8524/ © 2017 Elsevier Ltd. All rights reserved.

is strongly required for establishing the full scale industry of bioethanol.

Cost of cellulosic ethanol production mainly comes from three major sections of feedstock, cellulase enzyme, and non-enzyme conversion (Humbird et al., 2011; Liu et al., 2016). Currently, the conversion efficiency indicated by ethanol titer in fermentation broth (5–10%, v/v) (Humbird et al., 2011; Uppugundla et al., 2014; Kim and Dale, 2015; Chen et al., 2016) had been significantly modified and close to the level of corn ethanol production (12–15%, v/v) (McAloon et al., 2000). However, the high conversion efficiency is achieved generally under the prices of high energy consumption and wastewater generation in the step of chemical and inhibitor removal for elevating enzymatic hydrolysis and fermentation yields. The energy and water balance of lignocellulose biorefining is obviously unfavorable to that of the mature dry mill corn ethanol process in consuming higher fresh water, steam, electricity (McAloon et al., 2000; Aden, 2007; Ahmetovic et al., 2010), and generating much more wastewater (Martin and Grossmann, 2011; Sassner et al., 2008; Wingren et al., 2008). Considering the long term goal of cellulosic ethanol as gasoline alternative, the huge fresh water input and wastewater output may create a desperate situation, especially in developing countries such as China, Brazil, and India with the large agriculture industry and biomass production but insufficient fundamental systems. In the wide range of rural area of developing countries, the wastewater treatment system is extremely weak. The pollution to rivers and land by the small local industries has already generated huge environmental problems. It would be a disaster for these regions to implement of a high wastewater releasing industry. Furthermore, electricity supply is still a severe bottleneck for economic activity in many rural regions of developing countries. The huge wastewater generation and energy requirement by the conventional biorefining technology does not fit the reality of the developing countries for cellulosic ethanol industry. Therefore, the reasonable energy consumption and water balance are of special importance for not only it contributes a large portion of the overall cost, but also it determines the feasibility of technology penetration for the coming full scale industry.

This study designed an Aspen Plus model for the dry acid pretreatment and biodegradation (DryPB) biorefining process. The wastewater generation, the consumption and steam and electricity energy, as well as the MESP value were calculated based on the experimental data and modeling results. The results were compared with several typical biorefining process technologies for cellulosic ethanol production including dilute acid (DAP), ammonia fiber explosion (AFEX), deacetylation, mechanical refining (DMR), steam explosion (SE), and the dry mill process for corn ethanol production. With high ethanol titer, minimum wastewater generation and energy consumption, the MESP of DryPB is below \$2 per gal of ethanol, which falls into the cost range of corn ethanol production. The results indicate that the cellulosic ethanol production technology has already significantly advanced to the level for competing with corn ethanol production technology from both technical and economic viewpoint under the proper capital investment, feedstock logistic system and on-site cellulase supply chain.

2. Materials and methods

2.1. Biorefining technologies cited

Five typical lignocellulose biorefining technologies and one corn processing technology for fuel ethanol production were cited in this study. These process technologies are indicated by their unique pretreatment methods including the dry acid pretreatment and biodegradation (DryPB) (Liu et al., 2017), dilute acid pretreatment (DAP) (Humbird et al., 2010, 2011), ammonia fiber explosion (AFEX) (Uppugundla et al., 2014; Kim and Dale, 2015), deacetylation, mechanical refining (DMR) (Chen et al., 2015, 2016), steam explosion (SE) (Liu and Chen, 2016), as well as the dry mill process for corn ethanol production (McAloon et al., 2000; Wallace et al., 2005). The detailed information is shown in Table 1 and briefly explained as follows:

2.1.1. Dry acid pretreatment and biodegradation (DryPB)

Corn stover or wheat straw is milled to the size of 10 mm and dry acid pretreated at 175 °C for 5 min using 2.0 g sulfuric acid per 100 g dry biomass (Zhang et al., 2011; He et al., 2014a,b). The dilute sulfuric acid solution and the condensed water are completely adsorbed onto the solids to form 50% (w/w) of the dry pretreated feedstock solids. The pretreated corn stover or wheat straw solids is neutralized to 5.5 by Ca (OH)₂ suspension slurry, briefly milled to remove the extra-long fibers, and aerobically biodegraded at 28 °C and 0.8 vvm of aeration for 36 h (wheat straw) or 48 h (corn stover) (Zhang et al., 2010; He et al., 2016). Xylose and glucose released during the pretreatment are preserved without observable loss. The pretreated and biodegraded corn stover or wheat straw solids is enzymatically hydrolyzed at 50 °C, pH 4.8 for 12 h at 30% (w/w) solids loading and 10 mg protein/g cellulose of cellulase dosage. The simultaneous saccharification and co-fermentation (SSCF) is performed at 30 °C for 96 h by *Saccharomyces cerevisiae* XH7 (Liu et al., 2017).

2.1.2. Dilute acid pretreatment (DAP)

Corn stover is milled to the size of 4.1–5.8 mm and dilute sulfuric acid pretreated at 158 °C for 5 min using 2.2 g sulfuric acid per 100 g dry biomass. The pretreated corn stover slurry of 30% solid content is flash-cooled and neutralized by ammonia hydroxide. The hydrolysis is performed at 48 °C for 84 h at 20% (w/w) solid loading and 20 mg protein/g cellulose of cellulase dosage. The co-fermentation is conducted by *Zymomonas mobilis* 8b at 32 °C for 36 h.

2.1.3. Ammonia fiber explosion (AFEX)

Corn stover is milled to the size of 0.42 mm and ammonia fiber explosion pretreated at 140 °C for 15 min with 100 g anhydrous ammonia per 100 g dry biomass and 38% (w/w) solid loading. Ammonia and partial water are stripped by steam, then quenched, cooled, compressed, reheated and recycled to the pretreatment reactor (Bals et al., 2011). The ammonia-free biomass is cooled and hydrolyzed at 50 °C for 3 days with the cellulase usage of 30 mg protein/g cellulose and 18% (w/w) solid loading followed by the co-fermentation using *Saccharomyces cerevisiae* 424A at 33 °C for 120 h.

2.1.4. Deacetylation, mechanical refining (DMR)

Corn stover is milled to the size of 19 mm and deacetylated at 80 °C for 2 h using 50 g sodium hydroxide per 100 g dry biomass and 8% (w/w) solid loading. The black liquid is drained overnight. The solid part is again mixed with 12 folds excess of fresh water for 1 h and the residual NaOH is neutralized by adding sulfuric acid. The solids is drained and dewatered to the solid content of 45–50% (w/w). Two rounds of mechanical milling are performed on the deacetylated corn stover and then hydrolyzed at 50 °C for 120 h at 28% (w/w) of solid loading and 20 mg protein/g cellulose of cellulase usage, followed by the co-fermentation using *Zymomonas mobilis* 13-H-9-2 at 33 °C for 22 h.

2.1.5. Steam explosion (SE)

Corn stover is milled to the size of 20–30 mm and steam explosion pretreated at 180 °C for 24 min (Liu and Chen, 2016). The pretreated corn stover of 40% solid content is washed with a 15 folds excess of fresh water and then the solid/liquid separation is performed to obtain the solid (assuming moisture content of the solid is 50% (w/w) due to lack of detail data). The hydrolysis is performed at 50 °C for 12 h with 25 mg protein/g cellulose of cellulase usage and 20% (w/w) solid loading, followed by the co-fermentation using *Saccharomyces cerevisiae* IPE003 at 30 °C for 96 h.

2.1.6. Corn ethanol

Corn grain is hammer milled, continuously liquefied at 88 °C and 20% (w/w) solid loading, then heated to 110 °C for 20 min and saccharified in stirred tank at 60 °C for 6 h. The saccharified corn mash is cooled to 32 °C and fermented at 34 °C and pH 3.5 for 46 h. The ethanol

Download English Version:

<https://daneshyari.com/en/article/4996814>

Download Persian Version:

<https://daneshyari.com/article/4996814>

[Daneshyari.com](https://daneshyari.com)