Cellulose conversion in dry grind ethanol plants

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Abstract

The expansion of the dry grind ethanol industry provides a unique opportunity to introduce cellulose conversion technology to existing grain to ethanol plants, while enhancing ethanol yields by up to 14%, and decreasing the volume while increasing protein content of distiller’s grains. The technologies required are cellulose pretreatment, enzyme hydrolysis, fermentation, and drying. Laboratory data combined with compositional analysis and process simulations are used to present a comparative analysis of a dry grind process to a process with pretreatment and hydrolysis of cellulose in distiller’s grains. The additional processing steps are projected to give a 32% increase in net present value if process modifications are made to a 100 million gallon/year plant.

Keywords: Cellulose; Ethanol; Cellulose pretreatment; Cellulases; Corn co-products

1. Synopsis of key findings

This special edition of the journal addresses pathways for introducing cellulose conversion to dry grind ethanol plants. The papers that make up this special volume give experimental results, an engineering framework, and economic analysis for incorporating cellulose conversion technology into the dry grind pathway for fuel ethanol production from corn grain (Schell et al., 2007). The composition of wet cake and distillers dried grains with solubles, and changes in composition upon pretreatment using liquid hot water (LHW) or ammonia fiber expansion (AFEX) are utilized to develop material balances for processes that incorporate pretreatment into an existing corn to ethanol plant (Kim et al., 2007a,b,c). The liquid hot water and AFEX pretreatment processes represent “wet to wet” and “dry to dry” approaches, respectively, for cellulose pretreatment. Both pretreatments minimize monosaccharide formation during the pretreatment step itself. Formation of monosaccharides occurs after pretreatment when cellulases, hemicellulases, and/or other hydrolases are added (Fig. 1). A third type of pretreatment, based on chemical derivatization with phosphite esters results in some hydrolysis and nearly complete dissolution of DDGS in water (Oshel et al., 2007).
Both the liquid hot water (LHW) and AFEX pretreatments separate pretreatment from the hydrolysis step (Fig. 1). This minimizes the formation of monosaccharides during the pretreatment step, thereby also minimizing formation of sugar degradation products that can arise during this process. This concept separates pretreatment from the hydrolysis step, and thereby minimizes formation of monosaccharides and their degradation products during pretreatment. Liquid hot water (LHW) pretreatment achieves this effect by maintaining a pH of about 4–7 during a cooking step that is carried out at 160 °C for 20 min in liquid hot water (LHW). The AFEX pretreatment is an alkaline pretreatment for dry cellulosic substrate, with liquid ammonia added at an ammonia:cellulose ratio of 0.7–1, and at temperatures of 70–100 °C. Again, hydrolysis during pretreatment is minimized (Kim et al., 2008c). Phosphorylation of DDGS results in some hydrolysis, but also yields a water soluble mixture of oligosaccharides and other components (Oshel et al., 2008).

Pretreatments that form water soluble oligosaccharides provide opportunities for hydrolysis using plug flow reactors packed with solid phase acid catalysts. However proteins that dissolve during pretreatment adsorb onto catalyst surfaces and cause loss of activity unless the proteins are first removed (Bootsma et al., 2008). Currently, enzyme catalysts appear to be better suited than a solid phase acid catalyst for cellulose hydrolysis in distillers' grains.

Enzyme hydrolysis of the pretreated materials using Spezyme CP (Genencor, Palo Alto, CA) supplemented with β-glucosidase gives essentially complete conversion of the cellulose to glucose, but only partial conversion of hemicellulose to pentoses (Dien et al., 2008; Kim et al., 2008b). This latter phenomenon was found to be a function of enzyme composition. Addition of pectinases and feruloyl esterase to the cellulase preparation results in enhanced hemicellulose and cellulose conversion (Dien et al., 2008).

The hexoses from enzyme hydrolysis are fermentable by both a Saccharomyces yeast and by anaerobic Clostridium to either ethanol or butanol, respectively (Ezeji and Blaschek, 2008; Kim et al., 2008b,c). A material balance, together with a simulation of a dry grind process and a dry grind process retrofitted with a liquid hot water (LHW) pretreatment shows ethanol yields are enhanced by up to 14% if both glucose and xylose are fermented to ethanol and 9% for fermentation of glucose alone (Kim et al., 2008b). Economic analysis of the process shows a 32% increase in net present value when process modifications to achieve this enhancement are added to a 100 million gallon/year plant. This assumes an enzyme cost of $0.20 for each additional gallon of ethanol produced (Perkis et al., 2008) and inflation-adjusted capital costs for the equipment that makes up a corn to ethanol process.

Analysis of the environmental impacts of corn to ethanol production show that planting winter cover crops on land used to grow corn would reduce soil nitrogen loss and increase soil organic carbon levels, thereby enhancing environmental and economic performance of fuel ethanol plants (Kim and Dale, 2008).

2. Summary

The introduction of cellulose conversion technologies to dry grind facilities has benefits that outweigh the costs. Most importantly, dry grind facilities have the potential to provide test-beds for cellulose conversion technologies. The technology described in cited papers both enhances use of the major co-product of such plants, distiller's grains, and increases ethanol production. This improvement and the enhanced utilization of corn grain using cellulose conversion technology represent a significant, early step to bringing cellulose conversion to the ethanol industry.

References


Fig. 1. Pretreatment (a) acid pH, 150–200 °C. Hydrolysis reaction during pretreatment may form both G₀ (oligosaccharides), G (glucose), and D (degradation products and fermentation inhibitors). C is untreated, C * pretreated cellulose. (b) Liquid hot water pretreatment at pH 4–7, 150–200 °C; or AFEX pretreatment at 70–100 °C minimizes hydrolysis. Enzyme hydrolysis of the pretreated substrate at 50 °C is 100% selective for glucose. Degradation products are minimized. Analogous pathways may be presented for hemicellulose where HC, and HC * would represent untreated and pretreated hemicellulose, and in (a) xylose and arabinose together with associated degradation products would be formed while in (b) hydrolysis products would be xylose and arabinose instead of glucose.


