Quarterly Update

National Bioenergy Center Biochemical Platform Integration Project

Biomass

Biomass Program—Sustainable Fuels, Chemicals, Materials, and Power

October-December 2009, #25

The Biochemical Process Integration Task focuses on integrating the processing steps involved in enzyme-based lignocellulose conversion technology. This project supports the U.S. Department of Energy's efforts to foster development, demonstration, and deployment of "biochemical platform" biorefineries that economically produce commodity sugars and fuel ethanol, as well as a variety of other fuel and chemical products, from abundant renewable lignocellulosic biomass.

The National Renewable Energy Laboratory manages this project for DOE's Office of the Biomass Program. Information on the Biomass Program is available at Biomass Program.

To discuss the contents of this update, or for further information on the Biochemical Process Integration Task, contact Dan Schell at NREL, phone (303) 384-6869, email dan.schell@nrel.gov

R&D Progress

32nd Symposium on Biotechnology for Fuels and Chemicals

This Symposium will be held at the Hilton Clearwater Beach Hotel in Clearwater Beach, FL, April 19-22, 2010. Meeting information can be found at the following web site: http://www.simhq.org/meetings/sbfc2010/index.asp. A list of the technical session topics is as follows:

Monday, April 19
Session 1 – Biomass Microbial Strain Development
Session 2 – The Science of Biomass Recalcitrance
Poster Session 1

Tuesday, April 20
Session 3 – Biomass Enzyme Characterization and Catalysis
Session 4 – Hydrocarbon and Algae-Based Biofuels
Session 5 – Development in New/Improved Biomass Sources
Session 6 – Biorefinery Deployment and Industry Infrastructure
Poster Session 2

Wednesday, April 21
Session 7 – Biomass Sustainability and Land Use
Session 8 – Biomass Pretreatment and Fractionation
Evening Special Topics: International Bioenergy Centers Update

Thursday, April 22
Session 9 – Biomass Production and Logistics
Session 10 – Application of Biomass Enzyme Technology
Session 11 – Microbial Biomass Conversion
Session 12 – Bioprocessing and Separations Technology

Evaluating the Economic Impact of Solids Loading During Enzymatic Cellulose Hydrolysis

We determined the impact of solids loading on enzymatic cellulose hydrolysis of a dilute-acid-pretreated corn stover slurry using an experimental response surface design methodology. From the experimental work, we obtained an empirical correlation that expressed monomeric glucose yield from enzymatic cellulose hydrolysis as a function of solids loading, enzyme loading, and temperature. This correlation was used in a technoeconomic model to study the impact of solids loading on the minimum ethanol selling price (MESP). We first studied the process economics assuming that cellulose conversion yields remained constant as a function of solids loading, as illustrated in Figure 1. The empirical model was used to provide a more realistic assessment of process cost by accounting for changes in cellulose conversion yields at different solids and enzyme loadings as well as for different enzyme cost (see Figure 2). As long as enzymes are end-product inhibited, there is an optimum value for the total solids loading that minimizes the ethanol production cost. The optimum total solids loading shifts to higher values as the enzyme cost decreases. However, the exact value of the total solids loading that minimizes ethanol production cost is dependent on the enzyme's performance characteristics and cost. A manuscript on this work will be submitted for publication in January 2010.

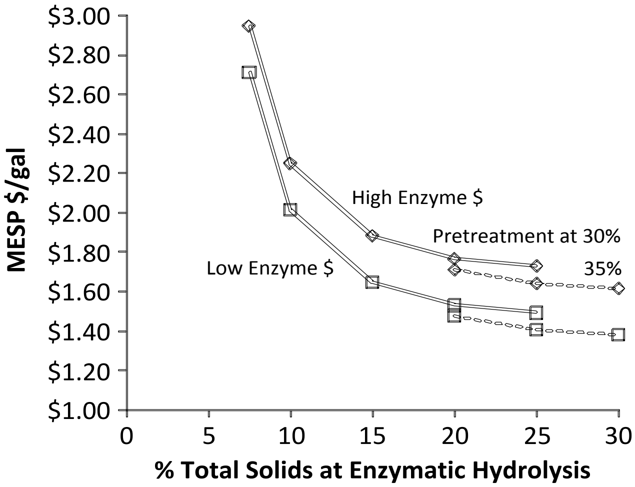

Figure 1. MESP as a function of solids loading assuming enzymatic cellulose hydrolysis conversion yield is not affected by solids loading. High enzyme cost was assumed to be $0.35/gal and low enzyme cost is $0.12/gal.

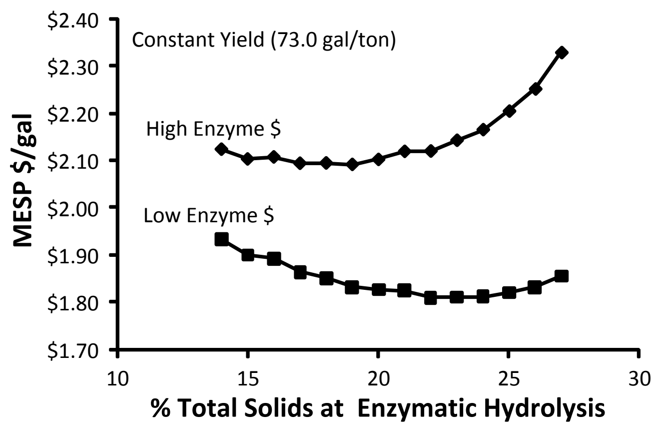

Figure 2. MESP as a function of solids loading when the empirical correlation is used to predict enzyme requirement at a constant ethanol yield of 73 gal/ton.

MIT Practice School

This fall, NREL hosted the MIT Practice School. The students performed several projects supporting our work in process integration. Two of those projects are discussed below.

Analyzing a Separate C6/C5 Process Configuration

This project focused on modeling a separate enzymatic hydrolysis and fermentation (C6) and hemicellulosic sugar fermentation (C5) process configuration. The work modified our current Aspen process model (Base Case, see 2002 Process Design Report at http://www1.eere.energy.gov/biomass/for_researchers.html) to incorporate the following changes:

1. Separate fermentation trains for the glucose and xylose streams
2. Two different beer columns for the glucose and xylose fermentation trains
3. Recycling the bottom stream from the second beer column (xylose stream) to dilute the cellulosic solids
4. Incorporation of experimental data on the performance of solid-liquid separation and washing steps.

The model was also modified to contain empirical expressions for enzymatic hydrolysis and fermentation reaction yields based on experimental data. The study found that the MESP for the C6/C5 configuration is lower than the Base Case by up to $0.09/gal, primarily because the C6/C5 process configuration achieves the same cellulose conversion yield using less enzyme. These results, of course, depend heavily on characteristics of the enzyme and microorganism used in this study.

Understanding Process Measurement Uncertainty

This project's main objective was to define error bounds on MESP caused by uncertainties in feedstock composition, yield estimates, and cost assumptions. The initial effort studied the impact of uncertainties in process variables and sample composition on the uncertainty in the calculated yield. It was found that the relative uncertainty in hemicellulose-to-soluble sugar yield is about 6%-10%. The main contributor to uncertainty is uncertainty associated with the fraction insoluble solids (FIS) measurement, with only minor contributions from the feed composition and process variables (e.g., feedstock flow rate and pretreated slurry flow rate). The relative uncertainty for cellulose-to-glucose yield from enzymatic hydrolysis was 24%, and again the FIS measurement dominated the uncertainty estimate. The second effort used a Monte Carlo analysis to calculate error bounds on MESP. Realistic probability distributions were assigned to various inputs required to calculate MESP including feedstock composition, yields of major reactions, and cost assumptions. The total error bound on MESP was found to be ±$0.24/gal.

2009 Task Member Publications

Dowe, N. 2009, "Assessing cellulase performance on pretreated lignocellulosic biomass using saccharification and fermentation-based protocols." In **Biofuels: Methods and Protocols**. Ed. Mielenz, J.R., Humana Press, NY.

Dutta, A., Dowe, N., Ibsen, K.N., Schell, D.J., Aden. A. 2009, "An economic comparison of different fermentation configurations to convert corn stover to ethanol using *Z. mobilis* and *Saccharomyces*." Biotechnol. Progress. Available on-line.

Hodge, D.B., Karim, M.N., Schell, D.J., McMillan, J.D. 2009, "Model-based fed-batch for high-solids enzymatic cellulose hydrolysis." App. Biochem. Biotechnol. 152, 88-107.

Templeton, D., Sluiter, A., Hayward, T.K., Hames, B., Thomas, S. 2009, "Assessing Corn Stover Composition and Sources of Variability via NIRS," Cellulose 16, 631-629.

Viamajala, S., McMillan, J.D., Schell, D.J., Elander, R. 2009, "Rheology of corn stover slurries at high solids concentrations – Effects of saccharification and particle size." Bioresour. Technol. 100, 925-934.

Weiss, N., Farmer, J. Schell, D.J. 2009, "Impact of corn stover composition on hemicellulose conversion during dilute acid pretreatment and enzymatic cellulose digestibility of the pretreated solids." Bioresour. Technol. 101, 674-678.

Wolfrum, E., Sluiter, A. 2009, "Improved Multivariate Calibration Models for Corn Stover Feedstock and Dilute-Acid Pretreated Corn Stover," Cellulose 16, 567-576.

Wolfrum, E., Lorenz, A., DeLeon, N. 2009, "Correlating Detergent Fiber Analysis and Dietary Fiber Analysis Data for Corn Stover," Cellulose 16, 577-585.

Zhu, Z., Sathitsuksanoh, N., Vinzant, T., Schell, D.J., McMillan, J.D., Zhang, P. 2009, "Comparative study of corn stover pretreated by dilute acid and cellulose solvent-based lignocellulose fractionation: enzymatic hydrolysis, supramolecular structure, and substrate accessibility." Biotechnol. Bioeng. 103, 715-724.

Biochemical Process Integration Task Information

Web-based information on the process integration project, including presentations made at past review meetings, are available at the following links: http://obpreview07.govtools.us/biochem/ and http://www.obpreview2009.govtools.us/biochem.

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