Thermochemical depolymerization of biomass carbohydrates

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Lignocellulosic biomass feedstocks offer a tremendous source of carbohydrates that have largely been untapped for conversion into value-added products via chemical and/or biological processes. The difficulty in liberating these carbohydrates from biomass materials in a cost-effective manner has been the primary hindrance to their widespread utilization in commercial processes. In comparison, starch-based carbohydrates have been used extensively in a variety of food, chemicals, and energy production processes, as efficient processes exist to liberate these carbohydrates in useable forms at high yields. With lignocellulosic feedstocks significantly less costly than starch-rich feedstocks, it is reasonable to assume that the development of efficient processes to depolymerize and recover soluble carbohydrates from lignocellulosic materials could greatly facilitate the growth of a ligniocellulosics-based industry for a variety of products.

Numerous methods have been investigated over the past several decades for the total and/or partial depolymerization of carbohydrates in lignocellulosic biomass, including a variety of thermal, chemical, and mechanical processes, and combinations thereof. Due to the wide heterogeneity of biomass materials, no one single process has been identified that has been widely accepted as the optimum process. Work at the National Renewable Energy Laboratory over the past two decades has investigated the response of woody biomass materials to various dilute sulfuric acid thermochemical processes. These processes include a full thermochemical hydrolysis of all carbohydrate fractions of biomass as well as a prehydrolysis of the hemicellulose fraction as a precursor to a subsequent enzymatic hydrolysis of the pretreated cellulosic residue. Process development efforts have been directed toward achieving higher process yields and/or reducing capital and operating costs to positively impact overall process economics while minimizing environmental impacts and process energy usage.

Several specific thermochemical dilute sulfuric acid processes are under investigation that appear to exhibit improved process performance characteristics. An extremely dilute sulfuric acid process (using a sulfuric acid concentration of less than 0.1% [w/v]) using a “shrinking bed” reactor configuration has been shown to achieve recoverable yields of both soluble xylose and glucose in excess of 90% of theoretical from yellow poplar sawdust. The use of extremely dilute acid (as compared to other dilute sulfuric acid total hydrolysis processes) reduces the subsequent neutralization requirement and, hence, the quantity of solid neutralization waste (i.e. gypsum) formed. This process may also have significant capital equipment cost savings, as the relatively mild acidic conditions may reduce the corrosion potential to allow for use of less expensive metal alloys for reactor construction.

Another extremely dilute acid pretreatment process configuration involves the use a flowing percolation reaction configuration to produce a pretreated substrate that is significantly more digestible by cellulase enzymes than pretreated substrates typically produced by traditional dilute sulfuric acid pretreatment approaches (up to 90% conversion of available cellulose to ethanol in a simultaneous saccharification and fermentation process in 48 hours using an enzyme loading of 25 FPU/g cellulose). Again, the use of extremely low concentrations of sulfuric acid has beneficial waste neutralization product impacts and potential reactor materials of construction cost savings. A variation of this process substitutes the continuous flowing percolation approach with a high solids batch or plug flow pretreatment process followed immediately by an elevated temperature washing (temperatures up to 150 C) of the pretreated solids. This process variation maintains much of the enhanced digestibility effect of the percolation process, but reduces the volume and temperature of the required liquid phase, resulting in a significant energy savings and overall beneficial process economic impact.