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Residence Time Distribution Measurement and Analysis of Pilot-Scale Pretreatment Reactors for Biofuels Production

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Residence Time Distribution Measurement and Analysis of Pilot-Scale Pretreatment Reactors for Biofuels Production

D. Sievers, *E. Kuhn, M. Tucker, J. Stickel, and E. Wolfrum*

Residence time is an important performance metric used for characterizing, modeling, and optimizing a chemical reaction system. Continuous reactors, such as horizontal auger tubes, typically have imperfect flow characteristics where undesired back-mixing and flow stratification lead to variations in residence time. This variation is characterized by the residence time distribution (RTD) curve, which describes the probability that a particle or chemical species will spend a specific time at desired reaction conditions. The variance about the mean time of this distribution is one indicator of how precisely the reactor is able to target a specific residence time. Tighter control of the RTD allows better control of reaction extent and ultimately the ability to maximize desired product yield.

Dilute-acid thermochemical pretreatment of lignocellulosic biomass for production of liquid transportation fuels is an example where understanding and controlling RTD is paramount. One key pretreatment reaction is hydrolysis of xylan to the desired intermediate, xylose sugar, which further degrades to furfural and other byproducts as the reaction proceeds. Maximal xylose yield is achieved at a specific residence time, but non-ideal flow inside continuous pretreatment reactors distributes species from the targeted reaction time and ultimately reduces the desired product yield. This is a particular problem when scaling up from batch-type laboratory reactor experiments, which have tight control of residence time. Several studies measuring RTD in polymer screw extruders are found in the literature, but the inhomogeneity and severity of pretreatment conditions present special challenges when extrapolating these techniques. Pretreating biomass slurry consists of moist variable-sized biomass particles with steam-filled voids that preclude several online measurement methods. High temperature, high pressure, and flashing of slurry at the reactor outlet also present difficulty for sample collection.

Measurement and analysis of RTD data is the focus of this study where data collection methods were developed specifically for the pretreatment reactor environment. Augmented physical sampling and automated online detection methods were developed and applied to 1 tonne/day horizontal auger tube-type and vertical vessel-type pretreatment reactors. Tracers were pulsed at the reactor inlet while outlet concentration was measured versus elapsed time. Quantification techniques included density, electrical conductivity, and spectroscopy. Both the measurement techniques themselves and the produced RTD data are presented and discussed.