Catalytic and Enzymatic Conversion of Lignocellulosic Sunn hemp fibres to Biofuel

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Abstract

We identify a new fast-growing non-edible cellulose-rich lignocellulosic energy crop, Sunn hemp fibre (*Crotalaria juncea*), for second generation biofuel production. However, physiochemical analysis shows that their high crystallinity, high degree of polymerization and low porosity make these fibres recalcitrant and resistant to the cleaving of the β-(1-4)-glycosidic bonds in their cellulose polymers. Here, we aim to find ways of overcoming these challenges by exploring various catalytic and enzymatic hydrolysis processes with disparate timescales (ranging from minutes to hours to days) for converting the long-chain cellulose molecules in Sunn hemp fibres to monomeric sugar.

Microwave-irradiated one-pot catalytic hydrolysis in the presence of ionic liquid and metal catalyst is found to rapidly break the glycosidic bonds of cellulose and produce glucose and other value-added platform chemicals from untreated Sunn hemp fibres in only 46 minutes. The water concentration and the reaction temperature are identified as the process parameters for regulating the product distribution. Then, we experimentally demonstrate how to employ chemical chaos via autocatalytic pathways to significantly enhance the product yields in 5 hours in oil-bath mediated catalytic conversion of pre-treated Sunn hemp fibres. Chaotic strange attractors with positive Lyapunov exponents and fractal dimensions appear in the non-equilibrium product phase space, enhancing the yields of biofuel precursors such as glucose, fructose, HMF, LA and FA, particularly where fractal dimensions and Lyapunov exponents are the largest. In enzymatic hydrolysis, we show that reactor mixing does not alter the non-competitive nature of product inhibition but reduces glucose and reducing sugar yields by enhancing product inhibition even while promoting mass transfer in the reactor.

We perform microbial fermentation of glucose obtained from all the above three hydrolysis processes. Optimization of the fermentation process shows the optimal temperature, mixing speed, and fermentation time for maximum bioethanol production to be 30°C, 40 rpm, and 15h, respectively. The maximum bioethanol yields (in gm of bioethanol produced/100 gm cellulose) are obtained as 30.4%, 25.5%, and 21.8%, respectively, for the above three hydrolysis processes, suggesting microwave-assisted hydrolysis for 46 minutes to be the best process for rapid, cost-effective biofuel production from Sunn hemp fibres and similar other recalcitrant cellulose-rich non-edible lignocelluloses.

Keywords: lignocellulosic biofuel; Sunn hemp fibre; Ionic liquid; Microwave-assisted catalytic hydrolysis; Temporal oscillations; Chemical Chaos; Fractal dimension; Lyapunov exponent; Enzymatic hydrolysis; Reactor mixing; Non-competitive inhibition; Microbial fermentation