Sustainable conversion of biomass waste to levulinic acid and hydrochar via wet torrefaction with H-Beta zeolite catalyst

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Significance and Relevance

Wet torrefaction (WT) is an effective pretreatment method of biomass waste for producing high-quality hydrochar and valuable liquid products. This study delves into how acid catalyst and reaction conditions in WT impact the resulting hydrochar's surface characteristics and elemental composition, as well as the distribution of liquid products. The focus is on utilizing wood cellulose pulp residue (WCPR) as the feedstock with H-Beta zeolite catalyst in a nitrogen-rich environment [1].

Introduction and Motivations

Biomass, known for its near carbon-neutral properties and abundant availability in nature, offers the potential to substantially decrease fossil fuel consumption and environmental pollution, particularly in reducing greenhouse gas emissions [2]. Cellulose, hemicelluloses, and lignin form the principal constituents of lignocellulosic biomass, accompanied by minimal amounts of organic extractives and inorganic minerals. Wood cellulose pulp residue (WCPR) is the leftover material that remains after extracting cellulose fibers from wood, a process achieved through physical, chemical, or biological methods, commonly used in several industrial sectors, particularly in the paper and pulp industry [3]. This residual material consists of various wood components that do not get transformed into cellulose fibers during the pulping process. Recent data provided by Statista reveals a consistent and robust performance in the global pulp industry, with production consistently exceeding 180 million metric tons on an annual basis for the past decade. In 2022, the global production of wood pulp experienced a notable surge, reaching over 195.8 million metric tons.

Materials and Methods

The H-Beta zeolite catalyst, featuring a SiO_2/Al_2O_3 ratio of 28, was procured from the commercial supplier Tosoh Corporation. This zeolite catalyst underwent a calcination process at 550 ◦C (10 ◦C/min) in the air for 6 h to remove impurities before being used in the study. All chemical reagents, calibration standards, and gases were commercially sourced and used without the need for further purification. Wet torrefaction of wood cellulose pulp residue (WT WCPR) reactions were conducted in autoclave steel batch reactors (6 Parr 5000 Multiple Reactor System), each with a capacity of 75 mL and equipped with online pressure and temperature control regulators [4].

Results and Discussion

The WT process involves a temperature range of 180–260 ◦C, and reaction durations spanning 15–60 min. The findings reveal that WT conditions, including the catalyst for WCPR, significantly influence the hydrochar's properties and liquid product distribution. With increasing temperature and reaction time, the hydrochar experiences changes, including increased carbon content and reduced oxygen content. The study identifies 260 ◦C and 30 min as the optimal temperature and time for levulinic acid production, achieving a remarkable selectivity of 62.8% with the H-Beta zeolite catalyst using H_2O/WCPR = 10. Various properties of the resulting hydrochar are assessed, including higher heating values (HHVs), decarbonization (DC), dehydrogenation (DH), deoxygenation (DO), enhancement factor, carbon enrichment, surface area, pore diameter, weight loss as well as solid, carbon, hydrogen, and energy yields. The WT + Beta_220 sample, processed at 220 ◦C for 30 min, exhibited the highest HHV at 30.3 MJ/kg and carbon content at 78.9% in hydrochar compared to various biomass types, with an enhancement factor of 1.51 and carbon enrichment of 1.63, while the sequence of element removal during WT prioritized as DO > DH > DC. Furthermore, it is worth highlighting that the most significant weight loss, increasing from 17.0 to 60.7%, was observed under the same WT conditions. Lastly, a

comprehensive reaction pathway is proposed to elucidate the WT of WCPR with the presence of H-Beta zeolite catalyst under these optimized conditions. In light of the acquired product distribution data and a thorough analysis of the existing literature, an extensive reaction network has been constructed aimed at providing a clear depiction of the trans- formation of cellulose into a diverse array of valuable chemical products. This transformation is achieved through WT WCPR catalyzed by an H-Beta zeolite catalyst, and it encompasses the production of various compounds, prominently featuring levulinic acid, 5-HMF, hydroxyacetone, furfural, formic acid, acetaldehyde, ethanol, methanol, acetic acid, and others, as presented in **Figure 1.**

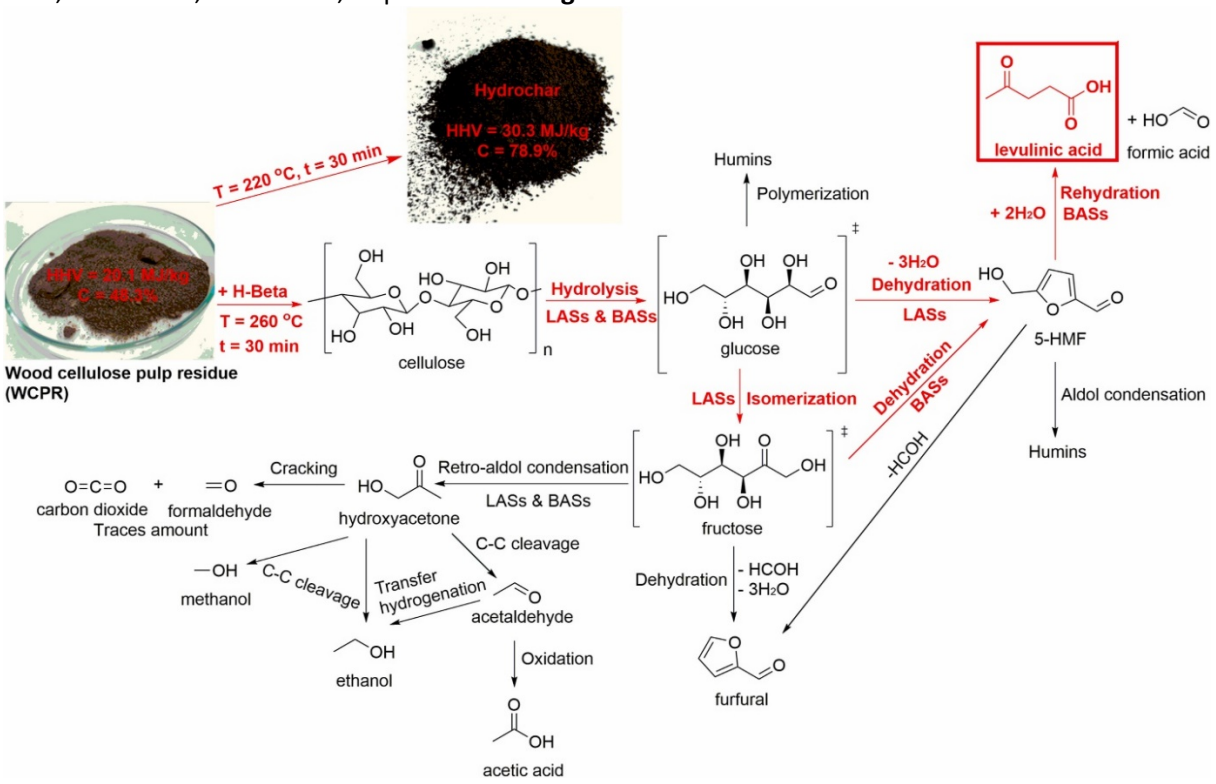

Figure 1. The reaction pathways for the WT of WCPR with H-Beta zeolite catalyst into hydrochar and the liquid value-added products.

References

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Acknowledgements

The authors acknowledge financial support from CARBIOW (Carbon Negative Biofuels from Organic Waste) Research and Innovation Action funded by the European Commission under the Horizon Europe Programme with grant agreement ID: 101084443. The authors are also thankful to BioTrainValue (BIOmass Valorisation via Superheated Steam Torrefaction, Pyrolisis, Gasification Amplified by Multidisciplinary Researchers TRAINining for Multiple Energy and Products' Added VALUEs), with project number: 101086411 (Horizon Europe, Maria Skłodowska-Curie Staff Exchange).