Stagewise Mechanical Pretreatment for Cost-Effective Clean Cellulosic Sugar Production

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Introduction

Pretreatment is currently recognized as a highly effective step to alter lignocellulosic structures and enhance saccharification. Most of the current biomass pretreatment methods rely on severe chemical-associated processing and are typically associated with high capital cost, severe environment burden, and inhibitory compounds for subsequent processing.

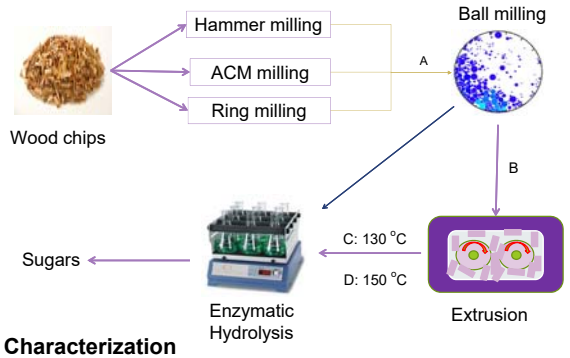
Mechanical pulverization of lignocellulose demonstrates a strong potential with high enzyme accessibility and less environment effect for facilitating sugar depot to produce fermentable sugars. The high electrical energy consumption is the major concern to the economic feasibility of scaling-up on a pilot. Taking into account these concerns, this research's goal is to demonstrate the feasibility of applying multiple step mechanical pretreatments to producing clean cellulosic sugars from forest residues on a pilot scale, minimizing the energy consumption of micronizing wood for hygrolysable substrates to make the method commercially viable. During the research, a three-stage mechanical process consisting of coarse/fine, amorphization, and fibrillation stages was developed as a potentially cost-effective route on an industrial scale. Coarse grinding such as hammer mill, ACM mill, and tandem mill involve different micronizing mechanisms to disrupt wood structure and hence generate different energy consumption level.

Objective

The goal is to demonstrate the feasibility of applying mechanical pretreatments to producing clean cellulosic sugars from forest residues on a pilot scale.

- To address the effects of different mechanical processing methods on the efficacy;
- To assess pretreatment processing unit operations for effective clean cellulosic sugar conversion
- To investigate feasibility of extrusion as a continuous mixing step to take place of the conventional mixing processing for industry and evaluate the effects of extrusion fibrillation on the sugar and energy consumption

Stagewise pretreatment processing

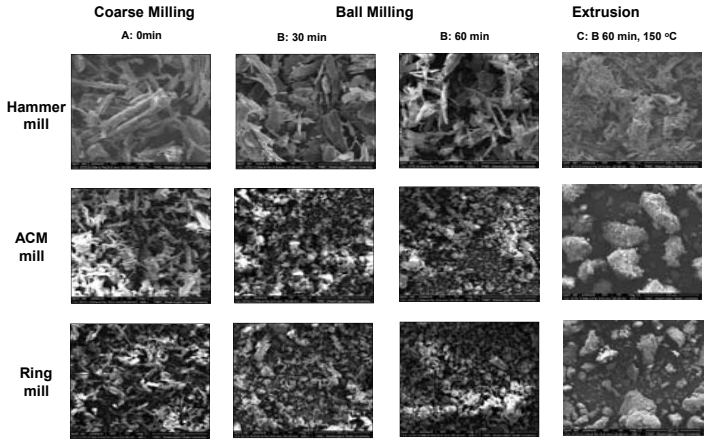


Characterization

Mechanical pulverization with Tandem mill, ACM-mill, Hammer mill, Ball mill, and Two-screw extruder

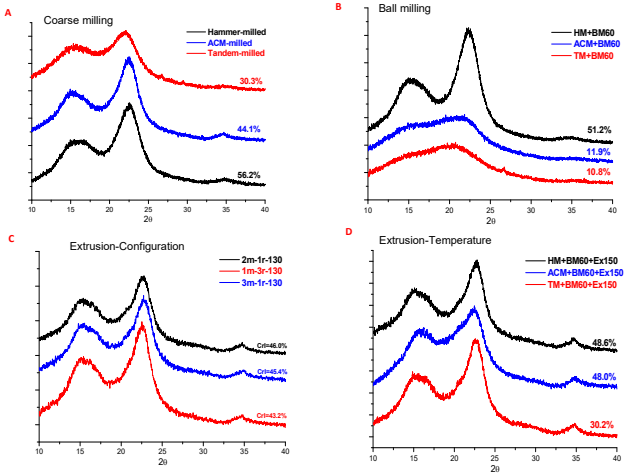
- Scanning electron microscopy
- X-ray diffraction
- Laser particle analyzer
- Energy consumption measurement
- Enzyme assay

Morphology



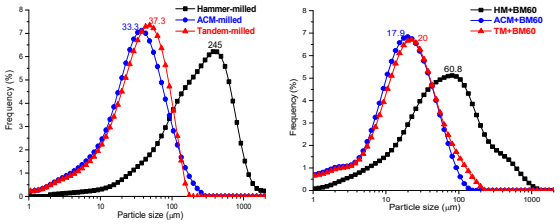
SEM micrographs reveal fiber delamination and cellular fragmentation of pretreated Douglas-fir

Crystallinity



Crystallinity of pretreated Douglas Fir, HM, ACM, TM (A); HM+BM60, ACM+BM60, TM+BM60 (B); HM, HM 3m-1r-130, HM 1m-3r-130, HM 2m-1r-130 (C); HM+BM60+Ex150, ACM+BM60+Ex150, TM+BM60+Ex150 (D)

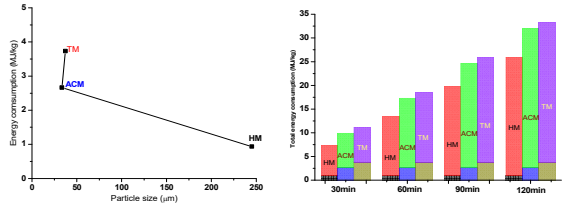
Particle size



Products A particle size distribution

Products B particle size distribution

Energy consumption



First stage Energy consumption of milling wood chip into products (A)

Total Energy consumption of milling wood chips into products (A+B)

Sugar yield from enzymatic hydrolysis

		Hammer mill	ACM mill	Tandem ring mill
Coarse milling	Glucose	9.60	17.7	35.8
	Xyl/Manose	2.40	7.80	13.8
Ball milling (60 min)	Glucose	19.7	71.0	79.6
	Xyl/Manose	10.7	37.1	30.5
Extrusion (150 °C)	Glucose	26.5	74.4	78.2
	Xyl/Manose	0.75	29.3	26.8

Conclusions/Recommendations

- Morphology and physical properties of multi-pretreated woody materials significantly changed. Specifically, particle sizes and crystallinity further decreased with ball milling treatment, thereby indicating better enzyme accessibility.
- With optimized grinding scheme, energy consumption can be lowered to be reasonable range for scale-up production
- Wood particles were apparently fibrillated through extrusion technology and particles size, morphology and crystallinity have been further changed under high shear force. However, the preliminary experiments indicated that there was no significant influence on sugar yield improvement. This is probably due to application of high temperature, bigger particle size, and recrystallinity during the fibrillation.

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