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Improved Biomass Deacetylation and Deconstruction using a Continuous Counter-Current Reactor

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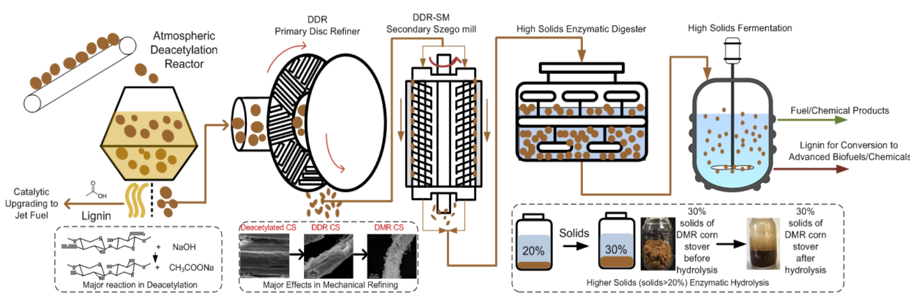
Abstract

Deacetylation and Mechanical Refining (DMR) process is an emerging technology that successfully demonstrated the capability to produce high titer, higher yield, low toxicity sugar and tractable lignin streams at low temperature atmospheric pressure conditions. Previous work has been performed all in batch stirred tank reactors with the scale up to 100kg/day. In this work we have adapted a shaftless inclined screw reactor to perform counter current deacetylation. Continuous counter-current extraction is practiced at the industrial scale in pulping processes to recycle the black liquor at high pressures/temperatures, enabling effective mass and heat transfer to achieve high lignin removal and efficient water/energy usages. Counter-current process steps enable high concentrations of the target compounds to be extracted into the extraction solvent and result in low residual content of the target compound in the extracted residue to increase efficiency and downstream product yields, while keeping the equipment more compact and decreased footprint dimensions compared to batch stirred tank reactors. Preliminary results have shown improved sugar yield in enzymatic hydrolysis at low enzyme loadings for the continuous counter-current deacetylation/mechanical refining process compared to the currently used batch process, while xylan losses into the black liquor are reduced up to 2/3.

Take Home Message

1. ***We successfully demonstrated continuous counter current deacetylation using a shaftless screw reactor.***
2. ***Continuous counter current deacetylation could potentially reduce xylan loss while maintaining and improving enzymatic hydrolysis yields.***
3. ***NaOH loadings in excess of 150 kg/tonne biomass show no yield improvements***

DMR Process



- Previous deacetylation research used batch processes
  - Labor intensive
  - Large reactors
  - Low production rates
- Need to achieve better deacetylation yields
  - Less xylan dissolution
  - Higher lignin removal
  - Less condensation of lignin

Future Work

1. ***Quantify and compare peeling reaction products from both batch and continuous process in order to understand and model the peeling reaction kinetics.***
2. ***Enable black liquor recycling to reduce chemical/energy usage and enrich valuable components such as glucose, xylan, and acetic acid for cost-effective utilization and recovery of the black liquor.***
3. ***Develop CFD models for the continuous counter current deacetylation in the shaftless screw reactor to evaluate the scalability of the process.***

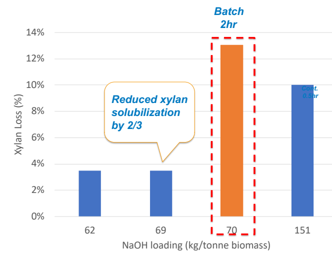
Material and Methods

- Key factors affecting continuous deacetylation
  - Residence time
    - Biomass feeding rate
    - Reactor angle
    - Screw speed
  - NaOH loading
    - Biomass feeding rate
    - NaOH feeding rate
    - NaOH concentration

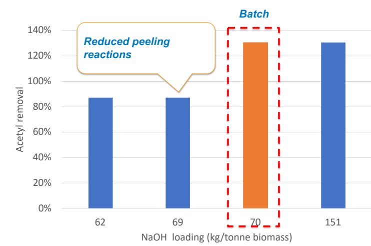
Experiment ID	Reactor Angle(°)	Biomass feed rate (air dired, g/min)	Nozzle No.	NaOH solution feed rate (gallon /min)	NaOH Conc. (g/L)	Residence Time (min)	Liquid: Solid Ratio	Total NaOH loading (g/kg bio-mass)
LTAD180807A	2	145	10	0.9	20	35	23.3	466
LTAD180807B	2	246	10	0.9	20	30	13.7	274
LTAD180807C	15	146	10	0.8	20	35	19.3	385
LTAD180807D	15	69	10	0.8	20	42	42.2	843
LTAD180807E	15	77	10	0.89	10	40	45.2	452
LTAD180807F	15	150	10	0.89	10	37	22.9	229
LTAD180807G	2	158	10	0.89	10	30	21.8	218
LTAD180807H	2	255	10	0.89	10	30	15.1	151
LTAD180807J	2	141	5	0.5	5.5	31	12.6	69
LTAD180807K	15	149	5	0.5	5.5	42	11.3	62
Batch	NA	NA	NA	NA	7.0	120	10	70

- Hypothesis:
  - Shorter residence times with better mass/heat integration in the counter-current deacetylation reactor reduces xylan dissolution and also reduces lignin condensation reactions, while keeping/improving deacetylation effects

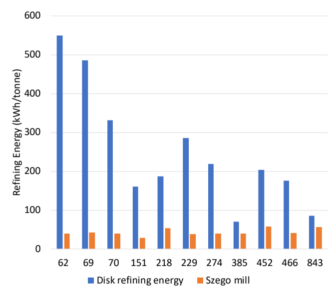
Results



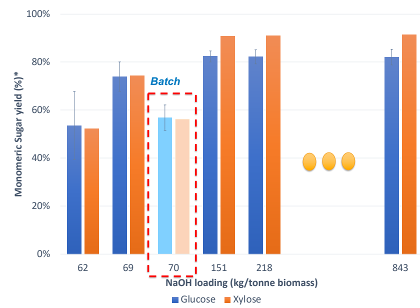
Xylan solubilization in black liquor was significantly reduced.



Acetate could be a degradation product from peeling reaction.



Disk refining is done using 12" disk refiner at NREL.



Enzymatic hydrolysis carried out at 20% solids with an enzyme loading of 12mg protein/g of cellulose.

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