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Investigating Residence Time Distribution (RTD) and Effects on Performance in Continuous Biomass Pretreatment Reactor Designs

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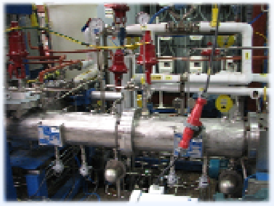
Background and Objectives



Pretreatment Reactor

Recent pretreatment work has focused on scaling from a batch process to a continuous process using a ¼ tonne/day continuous pilot scale horizontal pretreatment reactor. Lower xylose yields along with excessive xylose degradation in the form of furfural production were observed when comparing the continuous reactor to the batch reactor performance data at similar reaction conditions. These results suggest that the continuous reactor has a broader residence time distribution compared with the batch reactor producing an undesirable variance in pretreatment severity.

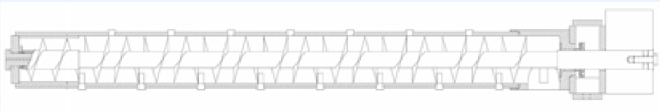
The continuous reactor is a horizontal pipe with a variable speed auger. Acid-impregnated biomass and steam are continuously fed to the pipe by a plug screw feeder and discharged at the other end to atmospheric pressure through two alternating ball valves. One continuous reactor configuration utilizes an auger with broken flights where rectangular baffles protrude from the bottom of the pipe into the flight breaks to facilitate mixing. Following initial experimentation, a new reactor section was designed and installed with a continuous flight auger and anti-rotation bars in place of the baffles in attempt to achiever better plug flow and reduce severity variance.

Batch vs. Continuous Reactors

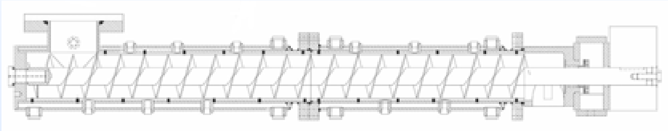
Operating Parameters and Results	Batch	Continuous
Temperature (˚C)	180	175
Acid Concentration (% w/w)	0.28	0.31
Mean Residence Time (min)	1.50	2.65
Severity*	2.5	2.6
Total Xylose Yield (%)	88	69
Monomeric Xylose Yield (%)	70	62
Furfural Yield (%)	3	10

$$* severity^{[1]} = \log\left(t \times \exp\left(\frac{T-100}{14.75}\right)\right)$$

[1] Overend, R.P., and Chornet, E. (1987). *Philos. Trans. R. Soc. Lond. (A).* 321, 523-536



Broken Flight Auger Reactor with Baffles

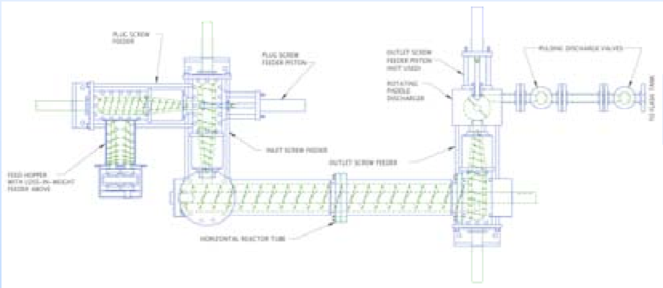


Continuous Flight Auger Reactor with Anti-Rotation Bars

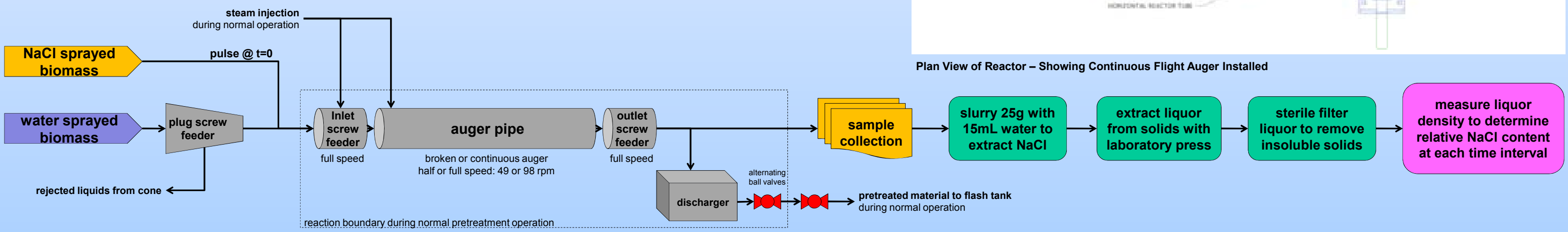
Materials and Methods

For RTD tests, the reactor was run at ambient temperature without steam addition due to pulse addition and sampled by hand. Water sprayed corn stover (45 wt% solids) was continuously fed through the plug screw feeder at 175 g/min, and material was manually collected as it entered the discharger section. A pulse was introduced into the reactor by pausing the plug screw feeder for 15 seconds and manually adding 15 seconds worth of sodium chloride impregnated corn stover at 60 wt% total solids at the outlet of the plug screw feeder. (Material normally fed through the plug screw feeder is dewatered to a level of about 60 wt% solids where excess liquid is discarded.) Biomass exiting the reactor at the discharger was collected in 15 second sample intervals for 10 minutes following the pulse addition.

Each biomass sample was mixed with a small amount of water to enhance sodium chloride extraction (typically 25g biomass with 15mL water). Liquor from each biomass sample was extracted using a laboratory press and sterile filtered to remove insoluble solids. The density of the resulting clear liquor was measured and used to calculate residence time distribution curves.



Plan View of Reactor – Showing Continuous Flight Auger Installed



Results and Conclusions

Calculated Plug Flow Residence Time (min)

Auger Speed	Broken Flight	Continuous Flight
49 rpm	1.31	0.62
98 rpm	1.14	0.42

Mean Residence Time (min)

Auger Speed	Broken Flight	Continuous Flight
49 rpm	2.70	2.14
98 rpm	2.65	2.04

Residence Time Variance (min²)

Auger Speed	Broken Flight	Continuous Flight
49 rpm	0.30	0.30
98 rpm	0.85	0.78

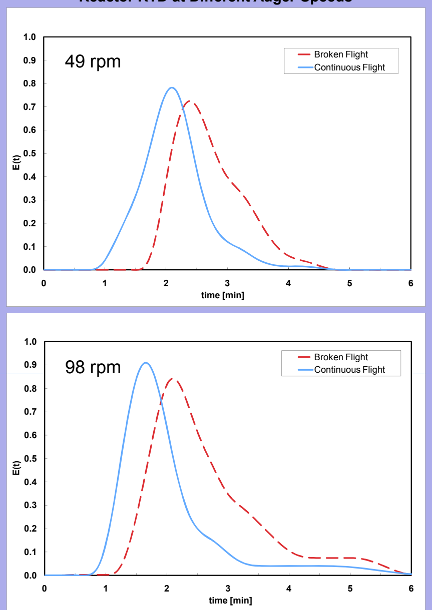
Residence Time Skew (min³)

Auger Speed	Broken Flight	Continuous Flight
49 rpm	0.12	0.15
98 rpm	0.96	1.38

Pretreatment Performance Comparison

Operating Parameters and Results	Broken Flight	Continuous Flight
Temperature (˚C)	175	175
Acid Concentration (% w/w)	0.31	0.28
Main Auger Speed (rpm)	98	98
Mean Residence Time (min)	2.65	2.04
Residence Time Variance (min^2)	0.85	0.78
Combined Severity*	2.6	2.5
Reactor Fill Factor (%)	1	1
Pretreated Material Solids Content (% solids)	28	28
Total Xylose Yield (%)	69	74
Monomeric Xylose Yield (%)	62	58
Furfural Yield (%)	10	12

Reactor RTD at Different Auger Speeds



- **Shorter mean residence times were measured in the continuous flight reactor.**
- **Residence time variance was not substantially different for either reactor.**
- **Residence time variance and skew are decreased for both reactor types at slower auger speeds.**
- **The continuous flight reactor produced**
  - **Higher total xylose yield (including oligomers and monomers)**
  - **Lower monomeric xylose yield**
  - **Higher furfural production**
- **RTD measurement method does not account for rheologic changes during steam pretreatment and does not consider reaction time in the discharger section.**

Although these results are less than ideal, this could be caused by failure to substantially reduce back-mixing in the reactor pipe. While the baffles and flight breaks have been removed, the anti-rotation bars in the continuous flight version do not allow the auger to span the entire inner diameter of the pipe. The reactor was operated with a low fill factor and this may subject a large fraction of the particles to back-mixing underneath the auger flights. The higher speeds have a much longer tail as shown by the higher variance and skew which is likely due to a further decrease in fill factor as auger speed is increased.

More work is necessary to decrease severity variance in this type of pretreatment reactor and a rapid, non-intrusive RTD measurement technique is also of high importance to ensure accurate reporting of residence times at pretreatment conditions. A full response surface experiment is under way that will provide comprehensive performance data using the continuous flight reactor.

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