Continuous liquefaction of pretreated lignocellulosic material with enzyme recycling (*LiqueFast™*)

We accept the challenge!
Disclaimer

Certain statements contained in this presentation constitute 'forward-looking statements.' These statements, which contain the words 'believe', 'intend', 'expect' and words of similar meaning, reflect management’s beliefs and expectations and are subject to risks and uncertainties that may cause actual results to differ materially.

As a result, readers are cautioned not to place undue reliance on such forward-looking statements. The Company disclaims any obligation to publicly announce the result of any revisions to the forward-looking statements made herein, except where it would be required to do so under applicable law.
Global Organization

Over 23,700 employees - 200 service and manufacturing around the globe
ANDRITZ Biorefinery and R&D Facility
Pruyns Island Technical Center – Glens Falls, NY

- 20,000 ft² (1,860m²) Laboratory Facility Opened in 1991
- Supports Corporate R&D and Sales Efforts
- Offering “Contract” Lab Services to Customers Outside Andritz
- Pulping & Biofuel R&D, Fiberline Process and Product Engineers
- Pulping and Biofuel Center of Technology
PITC Pretreatment System (batch steam gun)
Pretreatment Process

• The amorphous component of cellulose can be digested more easily by enzymatic attach than the crystalline component.

• The pretreatment process disrupts the lignin structure, and therefore, removes the physical barrier for enzymatic attach.

• The surface area is increased during pretreatment, thereby increasing the accessibility of cellulose to enzymes that convert the carbohydrate polymers into fermentable sugars.

• A partial hydrolysis occurs during pretreatment because of the severe conditions of high temperature and high pressure.

• Reduction in crystallinity, separation of hemicellulose, reduction in lignin content, and increase in surface area and pore size should be the achievement of an ideal pretreatment process.
Pretreatment effect
Two Stage Advanced steam explosion (ADV STEAMEX™) Process Concept
ADV STEAMEX™ Process Concept

- Spray Water
- Open Top Storage Silo (by others)
- Plug Screw Feeder
- Live Bottom Bin
- Stuffing Screw
- Steaming Vessel
- Pre-Treatment Reactor
- Steam
- MSD Impressafiner
- Inclined Drainer
- Stuffing Screw
- Blow Cyclone (3 bar(g))
- Swept Orifice Discharger
- Start-up Cyclone (Atmospheric)
- Atmosphere Cyclone
- To Heat Recovery
- Acid
- To Liquefaction Reactor
- Dilution / Cooling
- Flashed Vent to heat recovery
- Extracted C5 Sugars
- C5 Hydrolysate Flash Tank

Temperature Ranges:
- 130 – 170°C (~25 – 35 bar) 30-60 min
- 180 – 225°C (~10 – 25 bar) 1-2 (3) min
- 130 – 170°C (~2.5 – 8 bar)
Reactor Feed Equipment
ADV STEAMEX™ Process Concept
Pressure Profile Around Rotary Valve

18” Model 71 Depicted
Advanced Steam-Ex™ Process Concept

with Pre-Hydrolysis to extract dissolved Hemi’s before
Steam & Chemicals - Mixing Screw
Advanced Steam-Ex™ Process Concept

with Pre-Hydrolysis to extract dissolved Hemi’s before
Andritz Biomass Reactors

- Chemical Pulping Digester at Fibria, Tres Lagoas, Brazil. Start-up April 2009.
- Diam. 10.7m by 58m high
- Processes 7200 BDt/d of eucalyptus wood chips (~31 m³/min)
- Next plant sold to process 8200 BDt/d
Advanced Steam-Ex™ Process Concept
with Pre-Hydrolysis to extract dissolved Hemi’s before 180–225ºC (~10–25 bar) 1–2 (3) min 130–170ºC (~2.5–8 bar) 30–60 min <0.01s
Advanced Steam-Ex™ Process Concept
with Pre-Hydrolysis to extract dissolved Hemicelluloses
High Solids Saccharification processing

• It is very important to maximize the sugar released during enzymatic saccharification. For economic reasons, it is advantageous to perform the processes with **high-solids concentration**.

• Operating cost can be reduced with high-solids processing due to higher concentration of fermentable sugars in the product stream.

• Less water and energy usage, reduce disposal and treatment cost due to lower water usage plus smaller reactor sizes.
High solids pretreated material
Viscosity & Power correlation

• Biomass slurries pose mixing problems at high solids concentrations

• For pretreated material the high solids region begins at approximately 12%-15% TS

• The viscosities of biomass slurries increase rapidly above about 10% solids concentration as they are non-Newtonian fluids

• Conventional stirred tanks (CST) with conventional impeller configuration cannot effectively process slurries due to high power requirement.

• However, Andritz’s team have developed and liquefaction step where after the pretreatment, regular CST can be effectively used without the need of high power requirement
Viscosity & Power correlation

- Various reactor configuration have been developed to manage the high-solids slurries:
  - Ball mill, a theoretical continuous tower reactor design (Nguyen, 1998).
  - A paddle-impeller reactor of Tengborg et al
  - Attrition bioreactor (ABR) (Jones and Lee, 2004).
  - Horizontal paddle reactors:
    - Costly
    - Need several in parallel to accommodate for high capacities mill (size limitations)
    - Longer liquefaction time (>8h)
  - Fed batch configuration

- According to the following eq. (Tchobanoglous, 1991), the higher the viscosity of the fluid, the higher power required for processing

\[ P = k \mu N^2 D^3 \]

- **P**: Power consumption
- **K**: proportional constant
- **\( \mu \)**: viscosity
- **N**: impeller speed
- **D**: impeller diameter


Pretreated bagasse

Rotor spins at 2000 rpm during fast mixing and 200 rpm during slow mixing
From solids to liquid in less than 3h
Results

Dynamic viscosity at 20 rpm of pretreated lignocellulosic material during enzyme liquefaction at different premixing times with CTec3 3.5%

Enzymatic saccharification progression of pretreated lignocellulosic material

Yield (%)

Time (h)

0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 72 | 168

M X control: 2.95% 5.94% 7.39% 9.52% 10.59% 11.64% 12.46% 65.93% 62.25%
M X: 50 Hz 3h @ 15h: 2.64% 4.41% 6.15% 7.52% 8.56% 10.31% 11.54% 16.09% 41.21%
M X: 50 Hz 6h @ 15h: 2.3% 4.42% 6.77% 8.79% 9.61% 10.78% 12.26% 4.906% 84.395%
M X: 50 Hz 3h @ 0h: 7.76% 9.5% 11.6% 13.1% 15.2% 17.8% 22.24% 7.42% 20.93%
M X: 50 Hz 6h @ 0h: 2% 4% 7% 8% 9% 10% 11% 12% 13% 14% 2.2% 5.2% 12.16%
M X: 50 Hz 3h @ 0h: 2% 4% 7% 8% 9% 10% 11% 12% 13% 14% 2.2% 5.2% 12.16%
M X: 50 Hz 6h @ 0h: 2% 5% 7% 8% 9% 10% 11% 12% 13% 14% 2.2% 5.2% 12.16%
M X: 50 Hz 3h @ 0h: 2% 5% 7% 8% 9% 10% 11% 12% 13% 14% 2.2% 5.2% 12.16%
M X: 50 Hz 6h @ 0h: 2% 5% 7% 8% 9% 10% 11% 12% 13% 14% 2.2% 5.2% 12.16%
Density changes during trial 7 SE bagasse
20% TS

Density (g/ml)

0h hopper  0h bottom  1h bottom  2h mid  2h bottom  3h bottom

Density
Continuous Hydrolysis Lab System

Feedstock

Feed Pump

Enzymes

Enzyme Mixer

Continuous Hydrolysis Reactor
Continuous liquefaction reactor using CMC

Addition of different food colors shows plug flow pattern
Fluidization
Cooling solutions

- Pretreated material’s end temperature is high (90-100°C)
- Cooling is required before addition of enzymes (~50°C)
- Classic solution is adding chilled water to reduce temperature but as consequence %TS. As a result lower end sugars concentration.
- As a result of the fast liquefaction, the material is converted to a fluid and can be effectively cooled in conventional cooling equipment (heat exchanger)
- By recycling cooled, liquefied material to the fresh steam-exploded biomass, the biomass can be cooled without being diluted.
- As consequence also recycling of enzyme occurs
Liquefaction

Andritz Continuous LiquefaSTAT™ System

- Pre-Treated Feedstock
- Hydrolysis Buffer Tank
- Dilution
- pH Control
- Enzymes
- Blow cyclone
- Continuous Liquefication Reactor
- To Saccharification
Pilot scale system
Evidence of further viscosity reduction with recycling
Rheology characterization of fluids

- Rheology graph

![Rheology Graph](image)

- Thermoplastics
- Clay, Tar
- Sludge
- Paper pulp
- Grease
- Soap, Paint
- Water
- Gasoline
- Motor oils
- Beach sand
- Starch in water
Process configuration

- Fast liquefaction coupled with enzyme recycling and saccharification
Advantages of LiqueFast™

- Liquefaction is less than 3h
- Energy savings as no external cooling water required which would increase water usage and dilute sugars concentrations
- Large scale (mill size)
- Enzyme recycling which possibly reduces even further liquefaction time
• OUR VISION:
World market leader for high-tech production systems and services for pulp, paper, hydropower, steel, biofuel and other specialized industries.