Steam explosion

1. Biomass is saturated with steam, at high pressure during a short time (few minutes) 170°C < T < 240°C, 1 mn < t < 10 mn

2. A sudden decompression explosive decompression volatilization of the liquid water

Advantages of Steam Explosion:
- No chemical are used, only water
- Low energy consumption (short times)
- Up scaling (low investment & operating cost)
**Cellulosic ethanol**

**Sugar accessibility**

- Pretreatment > steam explosion

Goals of the pretreatment:
- Increase the surface area & porosity
- Partial removal of hemicelluloses
- Modification of lignin
- Reduction of cellulose crystallinity

- Abengoa (ABNT USA) in Kansa.

Large industrial facilities
500 tons-1000 tons biomass / day

Continuous steam explosion process
Recent Steam Explosion developments in LERMAB

- lab-scale batch prototype
- up to 270°C, 55 bars

non-conventional applications
1- Extraction of hemicelluloses from softwood

**Spruce sawdust**

- **Water impregnation**
  - 2 conditions
    - Neutral
    - Basic

- **Steam Explosion**
- **Liquid stream**
- **Precipitation (Ethanol)**
- **Dialysis**
- **Polysaccharide**

**Surface modification**
- Lignin droplets on the surface
- Peeling
- Cracks

**Increase of the surface area**
**Higher components extractability**

---

**Introduction**
- Hemicelluloses
- Metals
- Fibres
- Conclusion
Extraction in neutral conditions (water impregnation)

- Presoaking in water prior to steam explosion
- Yields of extracted polysaccharides (after precipitation & dialysis)
- For each T°C, decrease yields for long duration accompanied with formation of furfural + HMF
- Optimal yield: 190°C, 10 mn
In neutral conditions:  
~ selective extraction of acetylated galactoglucomannans

85% galactoglucomannans
- β-D-Manp 5
- β-D-Glup 1
- α-D-Galp 1

15% arabinoglycans
- β-D-Xylp 10
- α-L-Araf 1

10% w/w acetylated
Acetylation on C2 and/or C3 of mannose residues (HSQC)

Ferulates: 130 ppm

Keeping MM & the functionality

In basic conditions:  
selective extraction of arabinoxylans

90% arabinoxylans
- β-D-Xylp 10
- α-L-Araf 1.5

<5% glucomannans

DP ~ 100

DP ~ 500
Management of contaminated soils is a major environmental world-wide issue
- Industrial wastelands (massive pollution)
- Agricultural lands (diffuse pollution)

Utilisation of plants to stabilize / remove pollutants
→ accumulation of metals in the plants (contaminants translocation)

Harvesting to avoid contaminants dispersion / return to soil

Utilization of polluted wood and biomass for industrial applications (bioethanol, biorefinery...)
Management of the heavy metals to limit the recontamination

Two phytoremediation plants have been examined:
- A woody biomass: *willow short rotation coppice*
  - Low metals accumulation
  - Zn, Cd, Mn

- A grass: *noccæa*
  - High metal accumulation
  - Zn, Cd, Mn
**Proposed valorization pathway for phytoremediation willow**

**Introduction**

**hemicelluloses**

**Metals**

**Fibres**

**Conclusion**

**Willow short rotation coppice**

With bark

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose</td>
<td>43%</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>16%</td>
</tr>
<tr>
<td>Klason Lignin</td>
<td>35%</td>
</tr>
</tbody>
</table>

**Zn** 220 ppm  
**Mn** 26 ppm  
**Cd** 22 ppm

**Metals in solid residue**

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>t (min)</th>
<th>Zn</th>
<th>Mn</th>
<th>Cd</th>
</tr>
</thead>
<tbody>
<tr>
<td>180°C</td>
<td>2</td>
<td>60</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>200°C</td>
<td>5</td>
<td>40</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>220°C</td>
<td>8</td>
<td>20</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

**Increasing severity**

**Phytoremediation**

**Steam explosion**

**Enzymatic hydrolysis**

**Ethanolic fermentation**
**Proposed valorization pathway for phytoremediation Noccaea**

**Noccaea**

- **Cellulose**: 15 - 30%
- **Pectins**: 15 - 20%
- **Lignin**: 5 - 15%

<table>
<thead>
<tr>
<th>Metals</th>
<th>Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>2000</td>
</tr>
<tr>
<td>Cd</td>
<td>700</td>
</tr>
<tr>
<td>Mn</td>
<td>120</td>
</tr>
</tbody>
</table>

**Handout materials**

- **Steam explosion**
- **Solid pulp**
- **Enzymatic hydrolysis of the pulp**

**Graphs**

- **Metals in solid residue**
- **Enzymatic hydrolysis of the pulp**

**ABE Fermentation**

- **Clostridium acetobutylicum**
  - Sugars → Carb. acids, alcohols, solvents
3- Steam explosion of hemp. Fibres extraction
Cottonisation of hemp fibers by steam explosion

Optimisation through design of experiments
After water (without any chemicals) or NaOH fibers impregnation

Steam explosion

image processing

\[ D(\%) = \frac{\sum \text{(areas of unit fibers)}}{\sum \text{(areas of all the fibers)}} \times 100 \]
Optimal parameters: 4.1 min, 191°C. after NaOH (8%) impregnation
✓ defibration rate = 91.2%,
✓ ≈ 50% fibers with length < 3 mm
Short fibers, suitable for composite applications

Current developments in the fields of micro- and nano-fibers for composite applications

For textile applications, a process without chemicals has been selected
✓ Long fibers (2-5 mm) processable into yarns by cotton spinning systems
✓ High cellulose, low pectin/lignin contents
✓ Spinning & weaving of mixture hemp/cotton
✓ Industrial development in progress
• Versatile process for:
  - Energy production: 2G bioethanol, plateforme molecules, energy densification
  - Material applications: polysaccharides, lignin, fibers

• Not a lab oddity.
  - Industrial developments available.
  - Batch or continuous systems
Acknowledgements