Biomass pretreatment by a continuous flow of superheated steam

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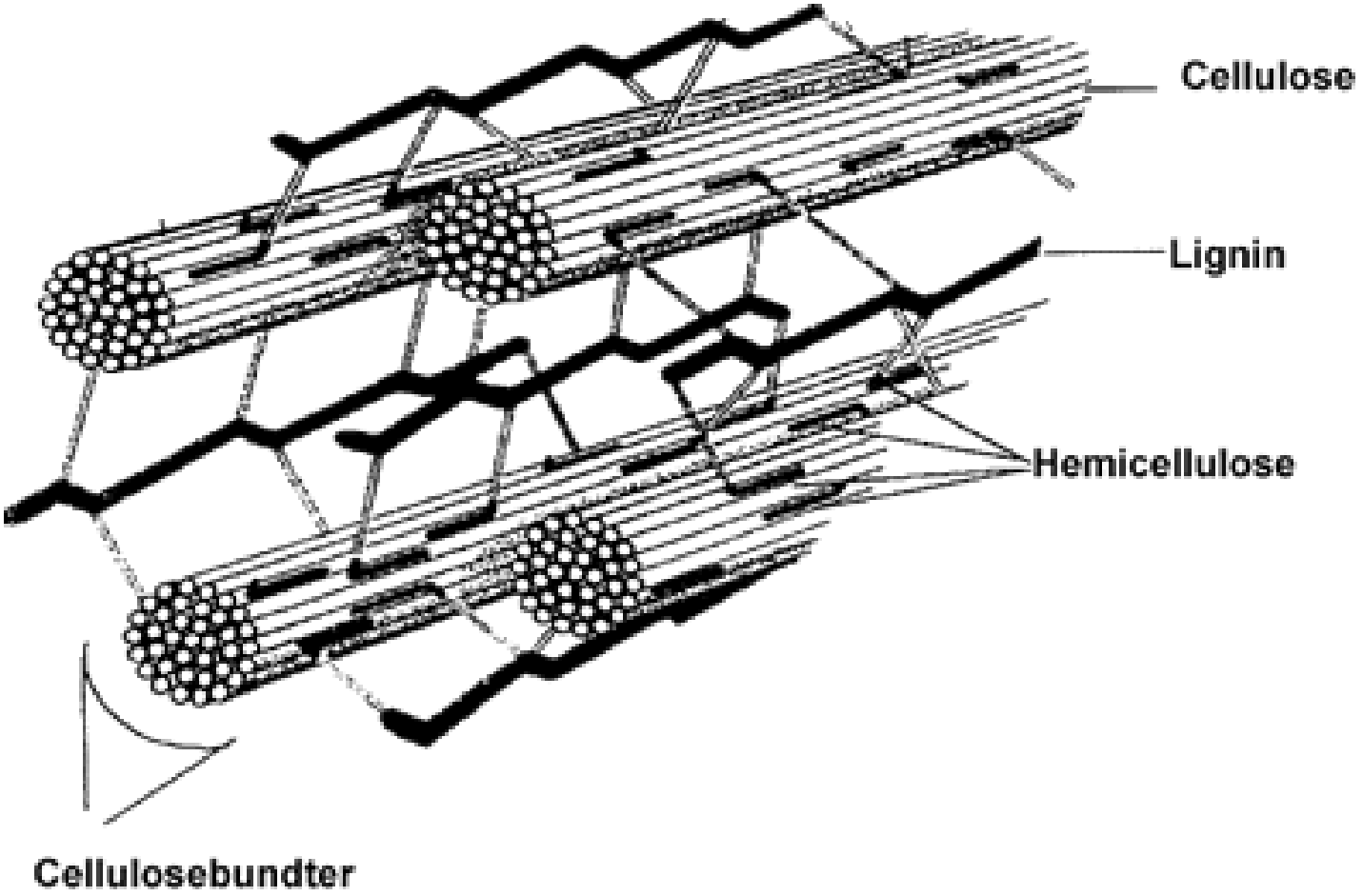
TNO innovation for life

The Netherlands Organization for Applied Scientific Research

- Established in 1932
- 4000 employees

Lignocellulose



Desired characteristics of lignocellulose pretreatment processes

- High accessibility of (hemi)cellulose for enzymes: > 90% monosaccharide production after enzymatic hydrolysis
- High dry matter concentrations
- Minimization of inhibitor formation
- Low use of energy and chemicals
- Low investment costs

Interesting options:

- Hemicellulose hydrolysed during pretreatment
- Cellulose decrystallization

High dry matter concentrations are important for the economy of thermal/acid pretreatment

- Lower amounts of water need to be heated
- Desired acid concentrations can be reached by adding limited amounts of acid

High dry matter concentrations are important for the economy of fermentation and downstream processing

Energy required for distillation and rectification:

Ethanol concentration in the beer	MJ/l ethanol (anhydrous basis)
5%	7.2
10%	4.8
15%	3.8

Novel dilute acid pretreatment process using superheated steam

Wheat straw (or grass or corn stover)
No need for cutting
Soaking in dilute sulfuric acid

Passing superheated steam (120-190°C) through heaps of straw.
Superheated steam is steam at a temperature higher than water's boiling point
= Dry steam
= Unsaturated steam

In contrast with stagnant and saturated steam

Heat transfer by convection, not by condensation.
Biomass gets dryer during the pretreatment

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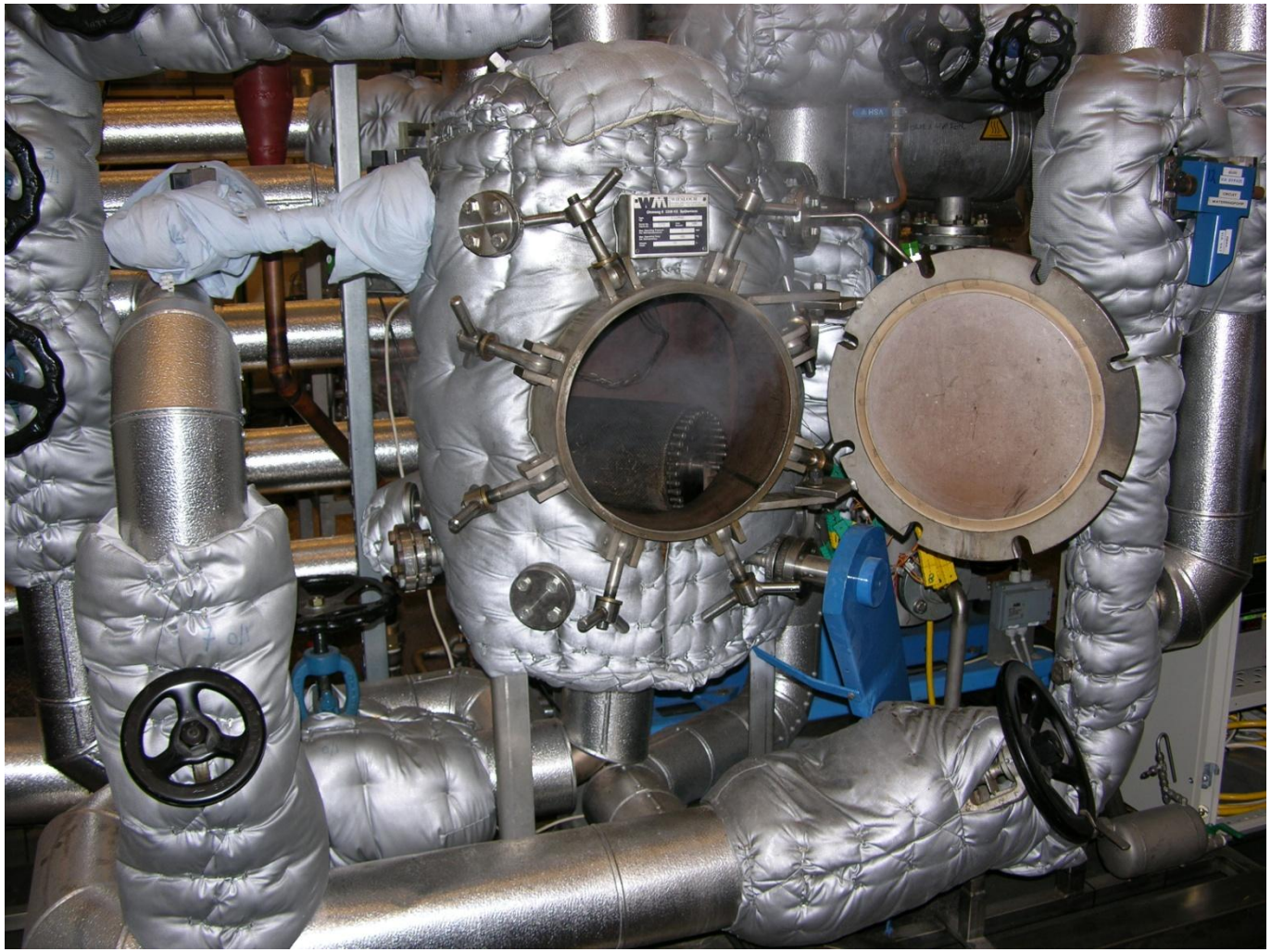
Continuous flow of superheated steam

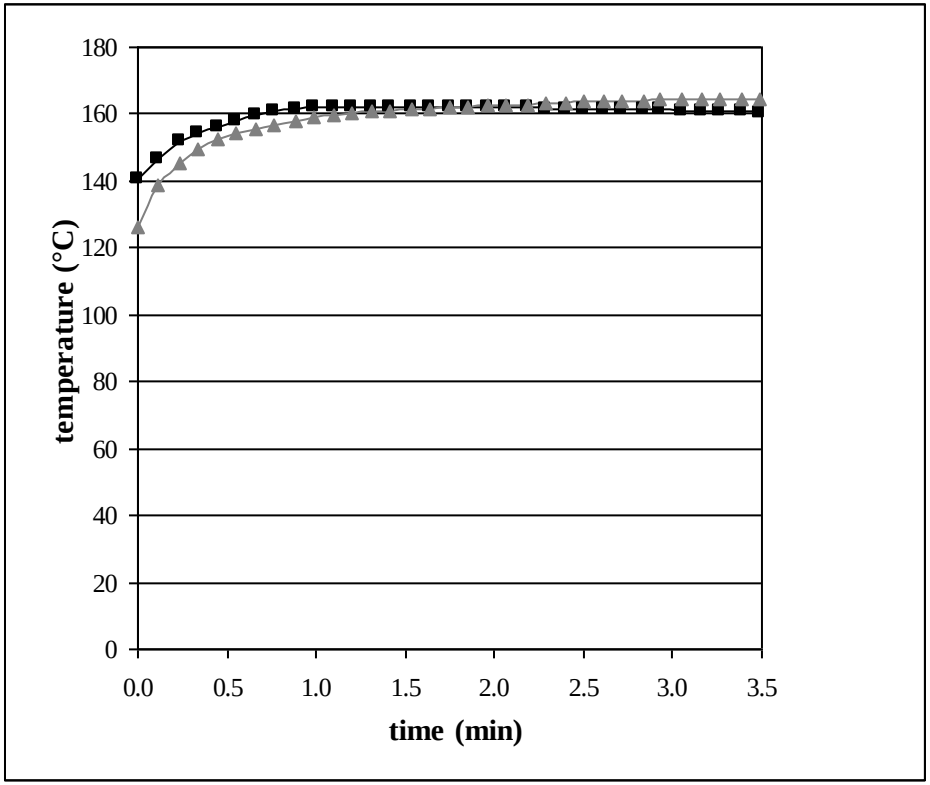
Superheated steam pilot plant

Superheated steam incubator



Wheat straw before and after dilute acid superheated steam pretreatment

BEFORE AFTER



Fast increase of temperature in straw heap

Monomeric sugars and degradation products after pretreatment

Component	Yield (mg g-1 DM)	Yield (%)
Glucose	13.0	3.8
Xylose	162.6	93.4
HMF	0.1	
Furfural	0.6	
Acetic acid	8.3	

Hemicellulose already hydrolysed in the pretreatment step.

Only need for cellulose degrading enzymes

Overview performance

- Wheat straw soaked in dilute acid (20-24% DM), heated with 5.5-6 bara SH steam

Temp. (˚C)	Reaction time (min)	Sulfuric acid conc. (%)	Final dry matter (%)	Glucose release after enz. hydrol. (% yield)
165	15	0.4	24	82
160	1.5	1.5	28	84
160	3.5	2.0	29	95
175	3.5	2.0	44	92
190	1.5	2.0	49	81
180	3.5	2.0	65	81

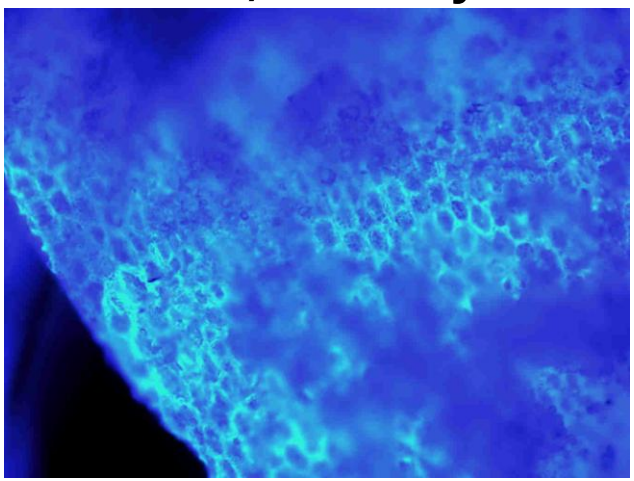
Evaporation of inhibitors

- Furfural and acetic acid are found in the steam condensate (20 mg furfural and 80 mg acetic acid/l).
- Test with furfural soaked straw (10 g/l). SHS treatment 6 bara, 160°C for 3.5 minutes. 97% furfural evaporated.
- Same test with acetic acid: 86% evaporated.

Ethanol fermentations

- Wheat straw with 41% w/w dry matter
- Without/with enzymatic pre-liquefaction
- Fermentation at 38% w/w wheat straw dry matter in SSF

Wheat bran; 85% dry matter, no added acid, Aw=0.5

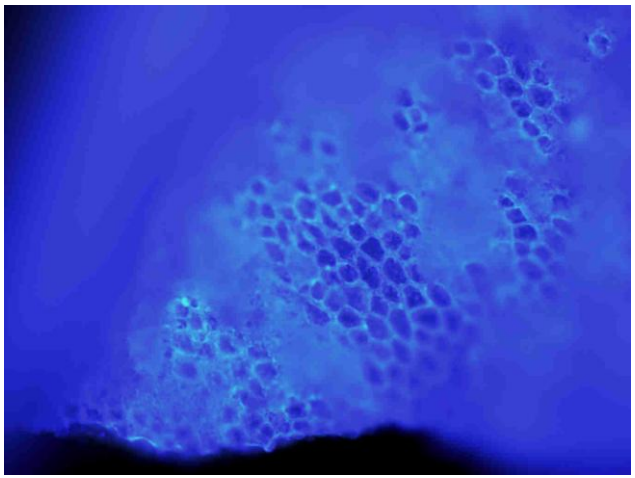


72,8 : 1

200µm

untreated

monster: controle

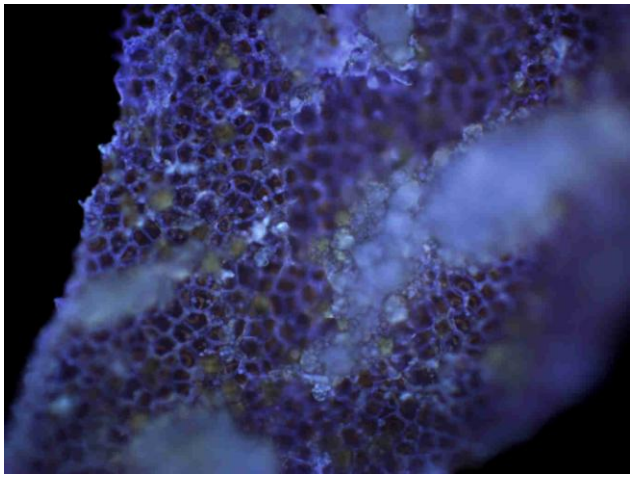


72,8 : 1

200µm

120°C

monster: monster A21



72,8 : 1

200µm

160°C

monster: monster A25

- Auto-fluorescence of lignin
- Notice the disappearance of light blue colour
- Diminished intensity of fluorescence suggests changes in cell wall matrix

Energy consumption of superheated steam pretreatment: 30,000 m³ bioethanol/year plant

12.7 ton wheat straw dry matter per hour (55,000 kW HHV)

Initial dry matter of 30% w/w

SHS dryer with circulating steam

Steam bleed of the evaporated water

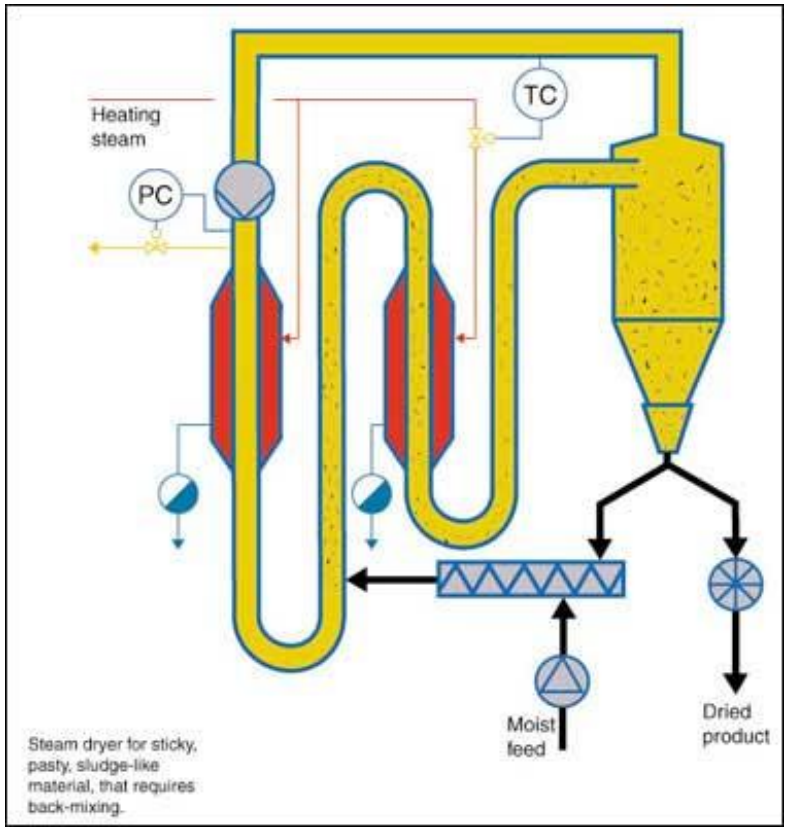
Conclusion:

Nett energy consumption is

4000 kW

Reuse in ethanol distillation

Examples of steam dryers



GEA Barr-Rosin/Stork “Exergy dryer”

BMA / NIRO
fluid bed dryer

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