The importance of impregnation in high kappa pulping

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Impregnation of cooking chemicals

- The impregnation is measured as alkali consumption.

- During the impregnation the alkali is mainly consumed by the neutralization of acidic groups.

- Two competing reactions:
  - Diffusion
  - Consumption
Impregnation
Chip cross section

Alkali concentration

Chip center

Alkali

OH⁻

OH⁻

Chip surface

Alkali

OH⁻

OH⁻

Chip surface
The diffusion of impregnation chemicals

The diffusion follows the equation below

\[ D = kT^{0.5} e^{E/RT} \]

\( E_a \) (diffusion) = 20 kJ/mol

Hartler and Onisko 1962
Alkali consumption at different temperatures

\[ k = A e^{-\frac{E_a}{RT}} \]

\[ E_a \sim 150 \text{ kJ/mol} \]
The rate of reaction is affected 50 times more than the rate of diffusion when the impregnation temperature is increased from 210°F to 290°F.
Visual difference between bad and good impregnation

Bad impregnation

Good impregnation

Karlström Thesis 2009
Chip cross section – kappa profile

Bad impregnation
High temperature
Kappa number

Good impregnation
Low temperature
Kappa number

A good impregnation results in an evenly cooked chip and a better selectivity. i.e. a more uniform pulp!
Heating without alkali results in lignin condensation

* DPM = Diphenylmethane type lignin structures

Funaoka et al 1991
Lignin condensation at a critically low alkali level
Problems with condensed lignin

- More difficult to delignify
- Variations in brightness (higher light absorption at low alkali charge)

Axelsson and Lindström 2004
Decreased alkali concentration – increased yield

Aurell and Hartler 1965
How can the consumption be slowed down?

Reduce the temperature!!!!!
How can lignin condensation be avoided?

Increase the L:W and reduced impregnation temperature!!!!

Increases the accessible alkali without increasing the concentration
Proper impregnation results in more narrow kappa number distribution

An impregnation at 110°C (230°F) makes chemical defibration possible at kappa 80 (Imp. time 120 min)

A less favourable impregnation results in wide kappa distribution (Imp time 11 min)

Karlström et al 2009
Improved impregnation – narrower kappa number distribution – less distribution in properties

Kappa

Reject, undigested parts

Over cooked parts, low carbohydrate yield

Weight% of pulp
It is easier to refine a homogeneous pulp more optimally

Schematic illustration based on Vikström M.Sc. Thesis 2009
An improved impregnation (EIC) increases the yield compared to the conventional technique (CK)
Effects of an improved impregnation

• A more homogenous pulp
• Less in-line and hot-stock refining
• Less shives
• Narrower kappa number distribution (less undigested parts)
• Increases the possibility to control the paper properties by doing more refining close to the paper machine
• A possibility to lower the kappa at the same yield
How can this be accomplished???

CompactCooking™ G2 with an ImpBin™
ImpBin™
Combined chip bin and impregnation vessel

Atmospheric degassing combined with a long, low temperature, black liquor impregnation

Well impregnated chips resulting in a homogeneous pulp with a very low reject content
ImpBin™

Upper part
CompactCooking™ G2 with ImpBin™
Black liquor addition is beneficial in SW cooking

*KWC = Dissolved Wood Components

Sjödahl 2006 PhD Thesis
The lignin concentration in the black liquor cook was 20 [g/L].

Sjödahl R
Possible mechanisms

- Phenolic lignin structures can work as buffer

- Phenolic structures can act similar to antraquinon

Phenolic group
$pK_a$-value $\sim 10$

Gierer 1980
Diffusion of lignin out of wood material

Lignin concentration ~1500 g/l

Inside wood material

Free liquor

Lignin concentration, g/l

- 100 g/l lignin in liquor
- 75 g/l lignin in liquor
- 50 g/l lignin in liquor
- 25 g/l lignin in liquor
Summary – importance of impregnation

- A reduced temperature and an increased time will favour the diffusion of cooking chemicals over the consumption during the impregnation.

- Black liquor addition increases the delignification rate during the bulk delignification.

- An improved impregnation results in a more narrow kappa number distribution.

- Makes it possible to operate at a lower kappa with the same or better yield.
What about the liner properties??
In-line refinery increases curl

- In-line refining is usually performed at consistencies between 9 – 15 %

Fibers with curl. Reduced refining gives straighter fibers!
Strighter fibers – increased tensile stiffness

Mohlin et al. 1996

Page et al 1979
Straight fibers – less mechano-sorptive creep

![Graph showing isocyclic stiffness index vs density](image)

- **Straight fibers, few microcompressions**
- **Straight fibers, many microcompressions**
- **Curled fibers, Many microcomprssions**
Straightener fibers - increased compression strength

Panek et al 2005
A reduced lignin content

Improves liner strength!
Lower lignin content - higher tensile stiffness

Antonsson et al 2009
Lower lignin content – less mechano-sorptive creep

<table>
<thead>
<tr>
<th>Isocyclic creep stiffness [kN/m/g]</th>
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<tbody>
<tr>
<td>EIC 60</td>
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<tr>
<td>EIC 75</td>
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<tr>
<td>CK 67</td>
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<tr>
<td>CK 73</td>
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Antonsson et al 2009

Byrd 1984 Tappi Journal 67(7) 86-90
Lower lignin content - lower hygroexpansion

Antonsson 2009
Summary – potential for kraft liner pulp improvement

• Lower kappa at the same yield
  - Increased tensile stiffness,
  - Less mechano-sorptive creep
  - Lower hygroexpansion

• Decreased in-line refining (straighter fibers)
  - Increase tensile stiffness (bending stiffness)
  - Less mechano-sorptive creep
  - Increased compression strength

• Makes it possible to reduce the grammage and make an equally strong liner from less pulp
Thank You

Questions??
References


Mohlin U-B Dahlbom J Hornatowska J., 1996, Fiber Deformation and sheet strength, Tappi J 79(6), 105-111


