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Elisabet Brännvall\*

# Increasing pulp yield in kraft cooking of softwoods by high initial effective alkali concentration (HIEAC) during impregnation leading to decreasing secondary peeling of cellulose

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**Abstract:** Pulp yield can be improved by a more homogeneous delignification of the chips, achieved by improved impregnation prior to the cooking stage. Complete and efficient impregnation is obtained by increasing the diffusion rate by means of an impregnation liquor with a high initial effective alkali concentration (HIEAC). In the present study, the effect of HIEAC in the impregnation was evaluated and compared to a reference impregnation procedure and a prolonged impregnation. After the various impregnation scenarios, the alkali concentration was always adjusted to the same level in the beginning of the cooking stage. Impregnation with a HIEAC resulted in yield improvements by 1–1.5% units, due to a higher cellulose yield and possibly also to higher yield of glucomannan. The HIEAC with an even alkali distribution within the chips prior to the cooking stage resulted in a more uniform delignification carbohydrate degradation. Yield increase obtained by uniform delignification is due to both decreased shives content as well as less secondary peeling.

**Keywords:** chemical composition, diffusion, high initial effective alkali concentration (HIEAC), homogeneous delignification, impregnation, kraft pulping, molecular mass distribution (MMD), peeling, pulp yield, softwood

## Introduction

High kraft pulping yields are crucial from economic and environmental points of view. There are several ways to improve pulp yield as discussed by MacLeod (2007). One way to achieve this goal is an improved pulping uniformity within the chips, which avoids under- and overcooked chip regions (Tichy and Procter 1981; Gullichsen and

Sundqvist 1995). Undercooked chip cores are lacking in chemicals at the beginning of the cooking process (Gustafson et al. 1989), which leads to the so-called rejects or shives. Shives can be recirculated back to the digester, but the yield from shives is much lower than that of the bulk cooking from wood. Re-pulping shives together with chips might even cause larger yield losses (Andrews and Hart 2013). The main goal is to provide a uniform cooking chemical distribution within the chips. Chip pre-steaming at higher pressure or for longer time periods prior to the addition of cooking chemicals improves their penetration and reduces the amount of rejects (Woods 1956; Hartler and Östberg 1959; Malkov et al. 2002). A specific impregnation stage operating at a lower temperature than the subsequent cooking also suppresses the reject formation (Tikka and Kovasin 1990; Tikka et al. 1993). The same is true for a prolonged impregnation time (Tolonen et al. 2010; Tavast and Brännvall 2017), but this approach decreases productivity and thus the high pressure approach is preferred (Malkov et al. 2002). Chip thickness reduction can also be a remedy, as thickness is the most critical dimension in impregnation (Akhtaruzzaman and Virkola 1979). Thinner chips need shorter impregnation times (Jiménez et al. 1990; Naithani et al. 2014) leading to fewer rejects and higher screened yields (Hartler and Östberg 1959; Hartler and Onisko 1962; Gullichsen et al. 1992, 1995; Tikka et al. 1993; de Morton et al. 2012). On the other hand, thinner chips may impair liquor circulation during cooking. Introducing cracks to chips may also shorten the transportation path of cooking chemicals with all the beneficial effects (Sainio 2000). The diffusion rate of chemicals increases with increasing temperature (Inalbon and Zanuttini 2008). The viscosity of the impregnation liquor decreases at higher temperatures, which contributes to the impregnation efficiency. However, increased temperature also results in elevated peeling reactions and hydroxy acids formation, which must be neutralized by alkali, which causes more alkali consumption. The latter is counterproductive as the alkali concentration in the chip is lowered (Egas et al. 2002; Brännvall and Reimann 2018). At 130°C, delignification reactions begin and initiate the first alkali consumption (Brännvall and Reimann 2018). The diffusion rate can be increased by a higher concentration gradient. A high initial effective alkali concentration

\*Corresponding author: Elisabet Brännvall, RISE Bioeconomy, Box 5604, SE-114 86 Stockholm, Sweden, e-mail: [elisabet.brannvall@ri.se](mailto:elisabet.brannvall@ri.se), <http://orcid.org/0000-0002-8992-3623>

(HIEAC) results in faster diffusion of alkali into chips (Määttä and Tikka 2012; Montagna et al. 2016) and decreases the formation of rejects (Santiago et al. 2008). HIEAC during impregnation with undiluted white liquor eliminates rejects and significantly increases the pulp yield (Gullichsen et al. 1995). This is an effective way to obtain an even alkali profile through the chip (Gullichsen and Sundqvist 1995; Gullichsen et al. 1995; Brännvall and Bäckström 2016; Brännvall and Reimann 2018).

In the 1970s and early 1980s, much pulping research was aimed at an extended delignification to decrease the lignin content before bleaching. As a consequence, less chlorinated aromatic compounds, such as dioxin, were formed. In the concept called modified kraft cooking (MKC, see Hartler 1978; Nordén and Teder 1979), one of the principles was a leveled-out alkali profile. In contrast to conventional kraft cooking (CK), where all alkali is added in the beginning of the cook, the alkali charged was split and added at two or more positions in a continuous digester. The MKC process has a better selectivity than CK in terms of pulp viscosity at a given kappa number (KN). Pulp viscosity was the focus of most of the scientific studies concerning MKC, while the pulp yield was rarely considered. The yield of the MKC process was supposed to be on the same level as that of CK (Nordén and Teder 1979; Sjöblom et al. 1988; Jiang et al. 1992) or slightly lower (Sjöblom et al. 1983a,b; Bäckström and Jensen 2001). Some of the calculations were indicative of a 0.5% MKC yield increment (Teder and Sandström 1985). However, the MKC process also has disadvantages. The cooking temperature in CK is usually 170°C, whereas in MKC it is lower, and consequently the pressure is also lower. At a higher temperature, the air remaining in chips is more compressed and detracts less from the impregnation with cooking liquor. Kovasin et al. (2003) found that air removal at lower temperatures is insufficient. Apart from slower diffusion due to low alkali concentration, an alkali-split can even lead to alkali depletion in chips (Jiménez et al. 1989; Walkush and Gustafson 2002). A low pH promotes lignin condensation and its precipitation from solutions. Peeling is less dependent on alkali concentration and occurs at low alkali concentrations (Wigell et al. 2007). In the case of alkali depleted chips, acid hydrolysis may degrade carbohydrates at elevated cooking temperatures, in the course of which new reducing end groups arise, which are initiation points of peeling reactions ending up in yield losses. HIEAC in the impregnation stage has no adverse effect on the final pulp yield (Santiago et al. 2008) in contrast to a low alkali concentration (Bäckström and Jensen 2001). The rapid displacement heating

(RDH) process resulted in higher yields with an initial effective alkali (EA) concentration of 0.9 M than in the case of 0.3 M EA concentration (Bäckström and Jensen 2001). The new trend in the MKC processes is no more than the KN decrement via extended cooking time, because the KN is decreased preferably in the oxygen delignification stage. Therefore, negative effects of HIEAC cannot be expected because this is performed at a low temperature. On the contrary, the yield increasing effects of HIEAC are well documented (Gullichsen et al. 1992, 1995; Brännvall and Bäckström 2016).

The aim of the present study was to investigate further the effects of HIEAC on the subsequent pulping stage with the pulp yield and the amount of rejects in focus. The essential impregnation parameters are 130°C, initial OH<sup>-</sup> concentration of 1.3 M (equivalent to 18% EA), a prolonged impregnation at same EA concentration at 105°C and HIEA with 24% (equivalent to 1.7 M EA). Independently of the impregnation scenarios tested, the alkali concentration at the beginning of the pulping stage will be adjusted to the same level to be able to see the effect of the impregnation stage on the delignification stage.

## Materials and methods

The varying moisture contents (MCs) of fresh chips (mixture of 70% pine and 30% spruce) were equilibrated to a MC of 8% by drying. The chips were screened and the fraction was 4–8-mm in chip thickness and the bark and knots were removed by hand. For impregnation and cooking, NaOH pastilles of puriss grade (VWR International AB, Radnor, PA, USA) and Na<sub>2</sub>S technical grade flakes (VWR International AB) were dissolved in deionized water to obtain stock solutions of each compound.

Impregnation and cooking were performed in steel autoclaves with a volume of 2.5 dm<sup>3</sup> with batches of 150.0 g o.d. chips. The chips were deaerated under vacuum for 30 min. Cooking liquor was prepared from the stock solutions to obtain 0.35 M [HS<sup>-</sup>] and an initial EA concentration either 1.30 M or 1.70 M. The liquor was sucked into the autoclaves; liquor-to-wood (L/W) ratio was 3.5 l kg<sup>-1</sup> wood. The autoclaves were heated in a steam-heated glycol bath at either 105°C or 130°C. The heating time to reach the temperature was 10 min, after which the actual impregnation time started. After finishing the impregnation, the autoclaves were cooled in a water bath before the EA concentration was adjusted. Two starting levels for the EA concentration were either 0.6 M or 0.5 M. To obtain the desired alkali concentration, the concentrations in the free and bound liquor after the different impregnation scenarios were taken into account based on the results from Brännvall and Reimann (2018), see Table 2. The free liquor volume after impregnation was 21 kg<sup>-1</sup> and that of bound liquor 1.5 l kg<sup>-1</sup>.

The L/W ratio in the cooking stage was 5 l kg<sup>-1</sup>. To obtain 0.6 M after HIEAC, the spent liquor after impregnation was diluted with deionized water. For the other two impregnation conditions, the addition of EA from the NaOH stock solution was necessary. To obtain 0.5 M after HIEAC, 100 ml of spent impregnation liquor was drained off and the EA level was adjusted by the addition of the Na<sub>2</sub>S stock

solution. For the other two impregnation conditions, no liquor was drained off and the alkali level was adjusted by the addition of NaOH stock solution. Na<sub>2</sub>CO<sub>3</sub> solution was added to both the impregnation and cooking liquors to obtain a carbonate ion concentration of 0.1 M. The [Na<sup>+</sup>] in the cooking stage was quite similar in all cases, ranging between 1.7 and 1.8 M. To verify the in-lab cooking reproducibility, duplicate cooks were performed in two cases, Table 1.

Residual alkali was determined according to SCAN-N 33:94 and HS<sup>-</sup> concentration according to SCAN-N 31:94 in duplicate. The carbohydrate composition was determined according to SCAN-CM 71, in duplicate, via acid hydrolysis followed by ion chromatography (IC). The method repeatability is <2.0% at 95% confidence level for total carbohydrate analysis, based on 10 duplicates, which includes uncertainty in dry content determination, sample weight determination, hydrolysis, dilution and IC. The carbohydrate composition is presented as polymers, the xylan content is calculated as arabinose+xylose, the glucomannan content as galactose+(1+1/3.5)×mannose and the cellulose content as glucose – (1/3.5)×mannose.

Limiting pulp viscosity was analysed according to ISO 5351:2010. The molar mass distribution (MMD) of cellulose was determined by size exclusion chromatography (SEC) with tetrahydrofuran (THF) as mobile phase. Prior to analysis, the samples were derivatized by tricarbonylation with phenyl isocyanate. The samples were dissolved in THF (approx. 0.5 mg ml<sup>-1</sup>) and filtered (PTFE syringe filter 0.2 μm). Some undissolved parts remained for all samples. The SEC system consists of

**Table 1:** Cooks with an initial EA concentration of 0.6 M after HIEA were repeated at two cooking times to check the reproducibility.

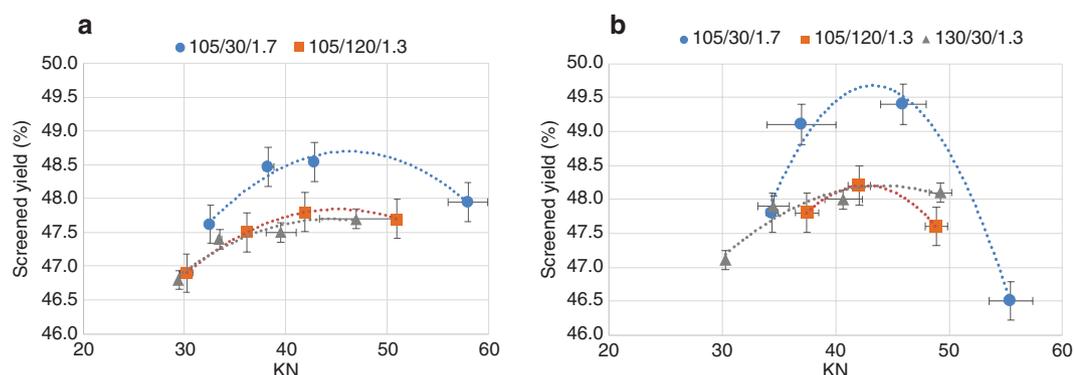
H-factor	KN	Rejects (%)	Screened yield (%)
1200	42.8	0.6	48.5
1200	44.2	1.3	48.6
Avr	43.5	1.0	48.6
SD	1.0	0.5	0.1
1400	38.3	0.4	48.5
1400	38.0	0.9	48.0
Avr	38.2	0.7	48.3
SD	0.2	0.4	0.4

a guard column, PLgel 10 μm Guard 50×75 mm, and three PLgel 10 μm MIXED-B LS 300×75 mm columns connected in series. The detection was performed using refractive index (RI) and UV<sub>280 nm</sub> detectors (Waters 410, Knauer, respectively). Calibration was performed with polystyrene standards with MMs from 3000 to 7 270 000. The calibration points were fitted to a linear function. MMD, peak MM (Mp), weight average MM (Mw), number average MM (Mn) and polydispersity (PD) index (Mw/Mn) were calculated by the Cirrus GPC software version 3.1 (Polymer Laboratories, Agilent). To get the MM of pure cellulose without tricarbonylation, the values from the SEC measurement were divided by 3.2 assuming a full degree of substitution.

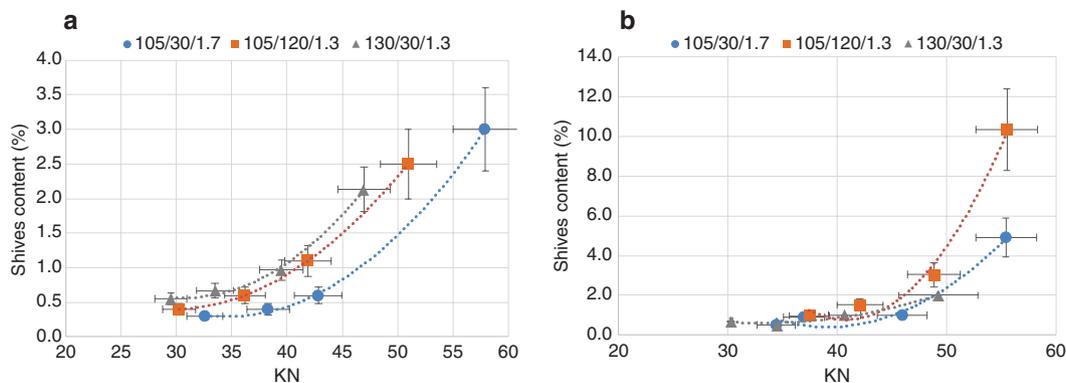
## Results and discussion

The cooking stage was always performed at 157°C and with the same calculated average EA and HS<sup>-</sup> concentration at the beginning of the cooking stage. Any differences with respect to delignification and carbohydrate degradation should thus be a result of the conditions employed in the impregnation stage. The following impregnation conditions were studied: (1) 130°C for 30 min with an initial [OH<sup>-</sup>] of 1.3 M (reference); (2) 105°C for 120 min with an initial [OH<sup>-</sup>] of 1.3 M; (3) HIEAC at 105°C for 30 min with an initial [OH<sup>-</sup>] of 1.7 M. The EA at the beginning of the cooking stage was adjusted either to 0.6 M or 0.5 M.

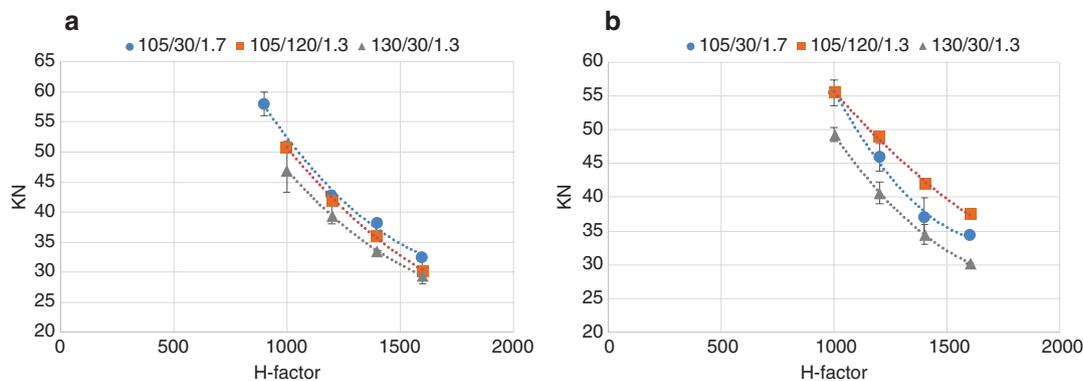
The screened yields of the pulps are presented in Figure 1. An elevated alkali concentration in the impregnation stage resulted in ca. 1% yield increment at both 0.6 M and 0.5 M initial alkali levels of the cooking stage. A similar positive effect on the yield of HIEAC has been reported by Brännvall and Bäckström (2016). Prolonging the impregnation at a lower temperature compared to the reference resulted in the same yield at a given lignin content. This is in contradiction to earlier studies, which reported an improved yield after prolonged impregnation (Wedin et al. 2010; Tavast



**Figure 1:** Effect of impregnation conditions (°C/min/[OH<sup>-</sup>]initial) on the screened yield at different degrees of delignification. EA concentration at the beginning of the cooking stage was 0.6 M (a) and 0.5 M (b). Error bars of KN show repeatability of duplicates on 95% confidence level.



**Figure 2:** Effect of impregnation conditions ( $^{\circ}\text{C}/\text{min}/[\text{OH}^-]_{\text{initial}}$ ) on the shives content at different degrees of delignification. EA concentration at the beginning of the cooking stage was 0.6 M (a) and 0.5 M (b). Error bars of KN show repeatability of duplicates on 95% confidence level.



**Figure 3:** Effect of impregnation conditions ( $^{\circ}\text{C}/\text{min}/[\text{OH}^-]_{\text{initial}}$ ) on the delignification rate. EA concentration at the beginning of the cooking stage was 0.6 M (a) and 0.5 M (b). Error bars of KN show repeatability of duplicates on 95% confidence level.

and Brännvall 2017). However, in experiments of Wedin et al. (2010), both the EA and the cooking temperature were lower in the cooking stage after extended impregnation than in the CK reference cook. Therefore, it was impossible to distinguish between the effects of EA and temperature. In the study by Tavast and Brännvall (2017), part of the spent impregnation liquor was removed prior to adjusting the average alkali concentration to the same level at the beginning of the cooking stage. Another difference to the present study was that the calculations to obtain a certain EA concentration were made under the only consideration of the EA in the free liquor and the assumption that also the bound liquor has the same concentration. As shown by Brännvall and Reimann (2018), the alkali concentration in the bound liquor can be quite different from the free liquor, and consequently, the actual alkali concentration was different at the beginning of cooking depending on the conditions of the impregnation stage.

The yield gain due to HIEAC was largest between KN 50–40, and at higher degrees of delignification the yield

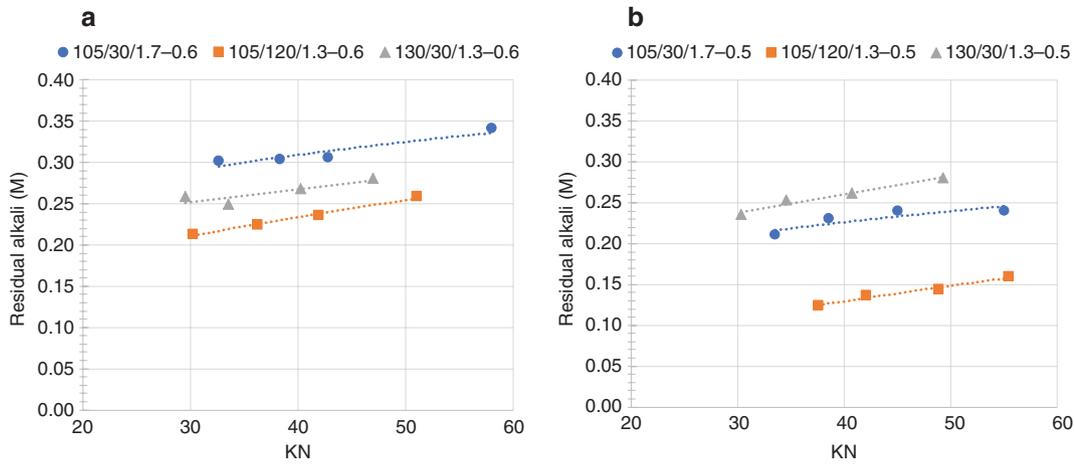
differences are diminishing. Paananen and Sixta (2015) found a pronounced yield advantage in the KN range 50–60 compared to CK with polysulfide pulping with HIEAC at low temperature. Accordingly, delignification selectivity optimum seems probably to be in this KN range.

As expected based on the results of Aurell and Hartler (1965), the IEAC in the cooking stage also affects the yield.

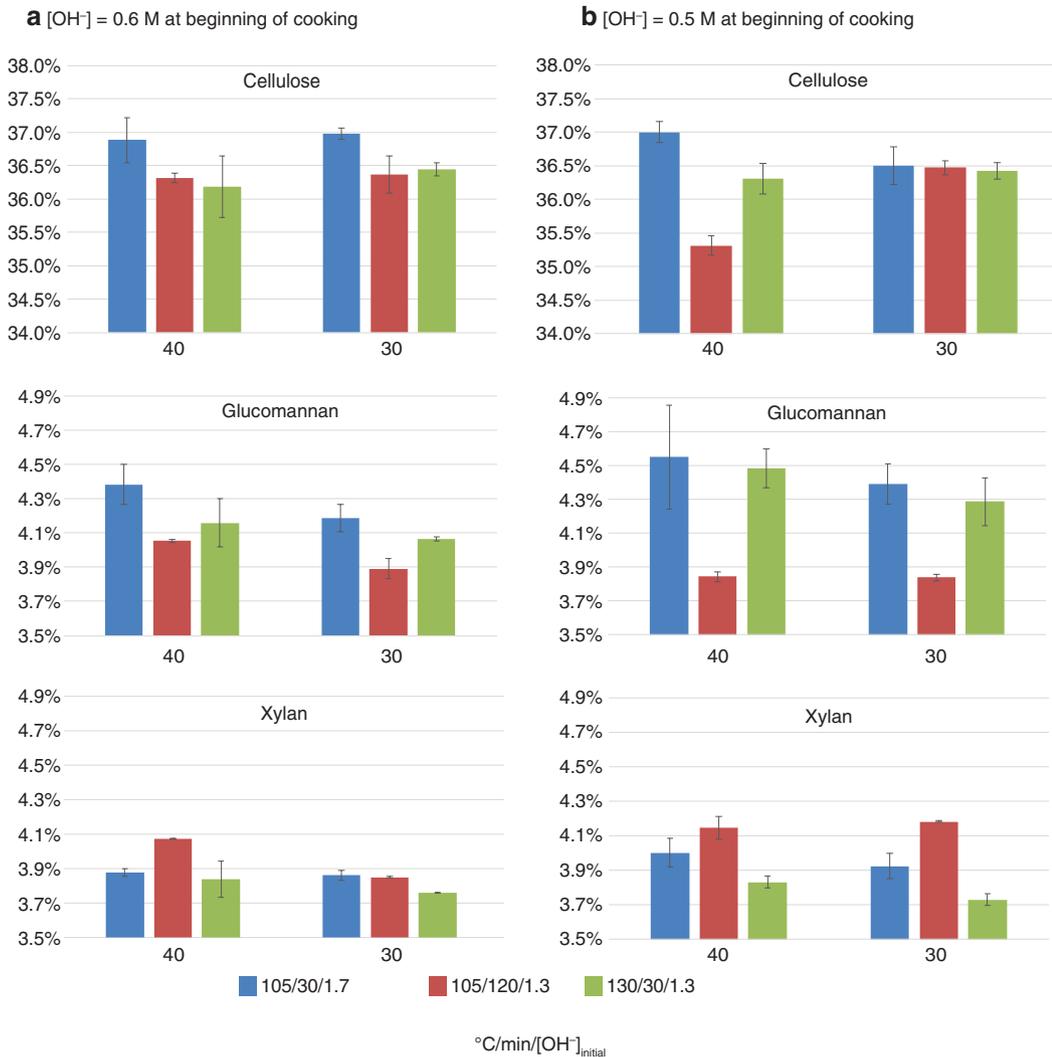
**Table 2:** Temperature, time and initial concentration of EA in impregnation and the alkali concentration in free and bound liquor after impregnation according to Brännvall and Reimann (2018).

Impregn. scenario	Temp. ( $^{\circ}\text{C}$ )	Time (min)	$[\text{OH}^-]_{\text{initial}}$	$[\text{Na}^+]_{\text{initial}}$	$[\text{OH}^-]_{\text{free}}^{\text{a}}$	$[\text{OH}^-]_{\text{bound}}^{\text{a}}$
HIEAC					0.9	0.7
Prolonged	105	120	1.3	1.85	0.5	0.4
Reference	130	30	1.3	1.85	0.5	0.2

<sup>a</sup>After complete impregnation.



**Figure 4:** Effect of impregnation conditions ( $^{\circ}\text{C}/\text{min}/[\text{OH}^-]_{\text{initial}}$ ) on the alkali concentration at different degrees of delignification. EA concentration at the beginning of the cooking stage was 0.6 M (a) and 0.5 M (b).

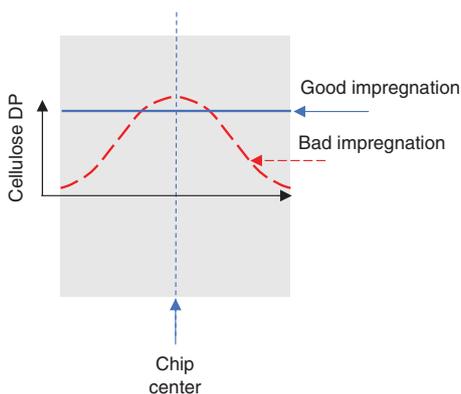


**Figure 5:** The effect of impregnation conditions on the yield, presented as % on wood, of cellulose, galactoglucomannan and xylan. The EA concentration at the start of the cooking stage was 0.6 M (a) and 0.5 M (b). Pulp with KN approximately 30 and 40 were analysed. Error bars show repeatability of duplicates on 95% confidence level.

Starting with 0.6 M resulted in 0.5–1% lower screened yields compared to the IEAC at 0.5 M.

HIEAC during impregnation increases the rate of  $\text{OH}^-$  diffusion into the chip and promotes a high and even alkali profile through the entire chip, and the risk of alkali depletion in the chip core is prevented. However, the yield increment in this case cannot be explained entirely by a lower shives content. At an IEAC of 0.6 M in the cooking stage, Figure 2a, HIEAC resulted in a lower shives content of about 0.5% compared to the other two impregnation scenarios, whereas the yield increment was 1%. With 0.5 M IEAC in the cooking, Figure 2b, no significant shives differences were noted in the KN range 30–45, and yet a significant screened yield increase was obtained.

An increased delignification rate and thereby less time for carbohydrate degradation reactions also contributes to



**Figure 6:** Illustration of cellulose molecular weight profiles through the chip in the thickness direction.

An even impregnation of chips with cooking chemicals gives an even reaction profile of alkaline hydrolysis through the chip and thereby similar viscosity through the chip (blue line). Inhomogeneous impregnation results in more alkaline hydrolysis at the chip surface (red dotted line).

yield increment. This is exemplified by the addition of  $\text{HS}^-$  to a soda cook; although no reactions between carbohydrates and  $\text{HS}^-$  occur, the improved rate of delignification preserves the carbohydrates. However, the delignification rate following HIEAC was not better than after the other impregnation cases, Figure 3. This could be due to the sodium ion concentration in the impregnation stage being slightly higher in HIEAC with 2.25 M, compared to 1.85 M for cases with lower alkali, see Table 2. Higher ionic strength has a retarding effect on the delignification rate, while Dang et al. (2014, 2016) demonstrated that a pulping initiated at a high ionic strength and continued after 30 min with low ionic strength led to a retarded delignification rate response. The higher ionic strength of HIEAC might affect the delignification rate in pulping in an analogous way. Additionally, chips after HIEAC and prolonged impregnation resulted in 2% higher remaining lignin content compared to the reference chips (Brännvall and Reimann 2018), which may also have contributed to a slower delignification.

Low residual alkali in the black liquor (BL) promotes yield as this deteriorates the solubility of dissolved xylan, which more readily redeposits on the fiber surface. The alkali level in the BL was however significantly higher when the pulping had been proceeded by a HIEAC impregnation and continued with pulping at an EA of 0.6 M, Figure 4a. At an initial EA of 0.5 M, however, the residual alkali was lower compared to the reference case, Figure 4b.

The reason for a higher yield after HIEAC is the lower degradation of carbohydrates. The cellulose yield was 0.5% higher in pulps with the HIEAC concept, Figure 5. This is in agreement with Brännvall and Bäckström (2016). At a delignification degree leading to KN 30, the screened yield was similar for the three impregnation cases when the cook was beginning at 0.5 M EA, Figure 1b, and in this case, the cellulose yield was similar as well. In all cases, HIEAC led to an apparently higher glucomannan contents, although

**Table 3:** Pulp viscosity,  $\eta$ , and MMD analysis.

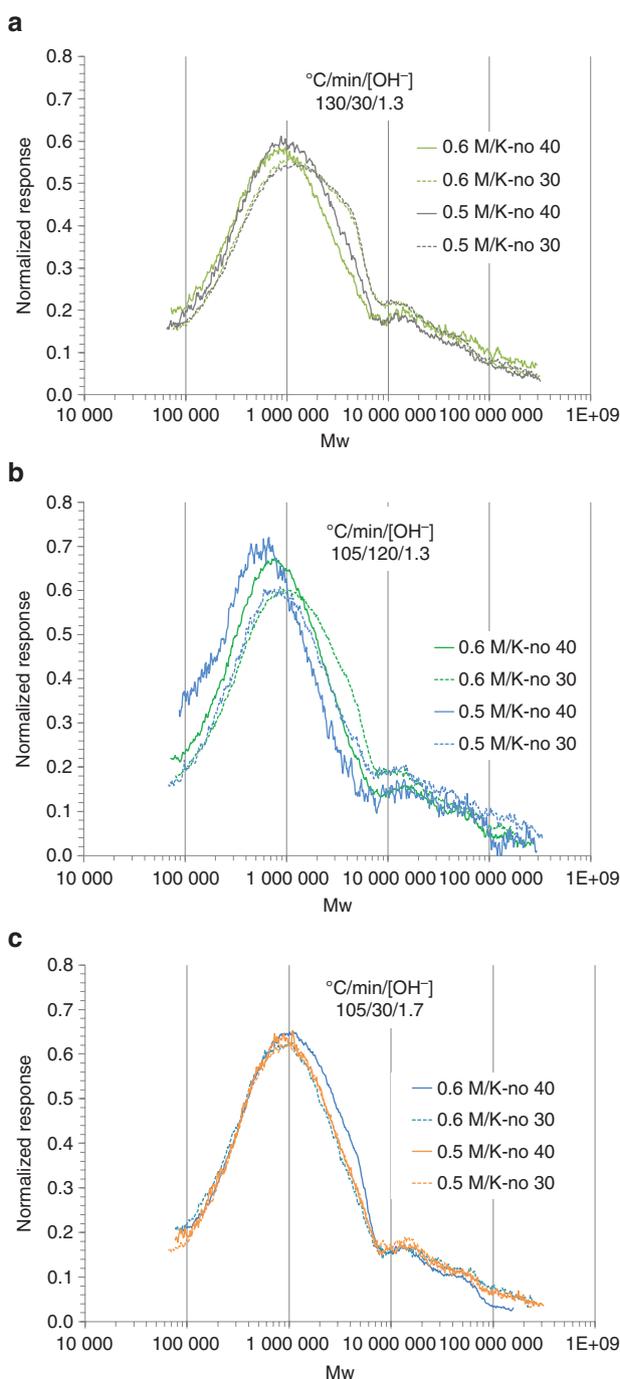
$^{\circ}\text{C}/\text{min}/[\text{OH}^-]$	Initial $[\text{OH}^-]=0.6$ M of cooking						Initial $[\text{OH}^-]=0.5$ M of cooking					
	KN	$\eta$ ( $\text{ml g}^{-1}$ )	Mole masses (kDa)			PDI	KN	$\eta$ ( $\text{ml g}^{-1}$ )	Mole masses (kDa)			PDI
			Mp	Mn	Mw				Mp	Mn	Mw	
105/30/1.7	42.8	1218	1008	578	7933	13.8	38.5	1227	1018	528	10 806	20.6
	32.6	1275	781	530	9710	18.3	33.5	1243	787	516	7669	14.8
105/120/1.3	41.9	1164	715	501	9260	18.4	48.8	1288	603	459	9766	21.2
	30.2	1150	947	582	8538	14.7	37.6	1291	813	551	12 692	23.0
130/30/1.3	40.2	1223	832	551	11 955	21.8	40.7	1208	956	559	10 695	19.2
	29.5	1243	997	604	10 354	17.1	30.3	1154	1143	645	11 629	18.0

The initial EA concentration of the cooking stage was 0.6 M or 0.5 M. Pulps at KN  $\approx$  30 and  $\approx$  40 were analysed.

the differences are not statistically significant. However, also Brännvall and Bäckström (2016) obtained higher glucomannan yield by high effective alkali impregnation (HAI) and it is not improbable that this process indeed preserves some glucomannan due to the stopping reaction being promoted by high alkali (Paananen and Sixta 2015).

Alkaline hydrolysis leads to the formation of new reducing end-groups in the carbohydrate chains, which are subjected to secondary peeling and cause the main yield loss of cellulose (da Silva Perez and van Heiningen 2015; Paananen and Sixta 2015). Unfavorable impregnation conditions may result in viscosity profiles through the chip, illustrated by the red dotted line in Figure 6, while an even impregnation would have more similar viscosity values in all parts of the chip, illustrated by the blue line. The occurrence of viscosity profiles has been measured and modeled by Li et al. (2000).

The viscosity gradients through the chip thickness may thus also be interpreted as yield profiles. Grénman et al. (2010) modeled dissolution of lignin and hemicelluloses in a wood chip, showing large differences in concentration between the chip surface and center as degradation and dissolution start at the surface. Jiménez et al. (1989, 1990) presented a model showing large lignin concentration gradients in the chip thickness direction for poorly impregnated chips and it has been shown that pulps with the same KN may have quite different distribution in lignin content (Gullichsen et al. 1992; Jääskeläinen et al. 2003; Malkov et al. 2003; Rayal et al. 2005). It is likely that these gradients in lignin and hemicellulose dissolution also represent gradients in cellulose degradation; a more even impregnation is expected to result in higher average molecular mass of the cellulose and a narrower molecular mass distribution (MMD). However, in this study, neither the pulp viscosity, giving an average value for the molecular mass of carbohydrates in pulp, nor the calculated average molar weights after SEC analysis show a clear trend depending on impregnation conditions, Table 3. On the other hand, when studying the entire chromatograms from the UV detection, Figure 7, an interesting comparison can be made. It is evident that cooking after HAI resulted in very similar MMD whether the EA at the beginning of cooking was 0.6 M or 0.5 M or the KN of the pulp was 30 or 40. Both reference impregnation and prolonged impregnation resulted in large variations in MMD. This can be interpreted as chips subjected to HAI are homogeneously pulped whereas both pulping after the reference impregnation case and prolonged impregnation lead to heterogeneous pulping. In the two latter cases, higher degrees of delignification led to an increased fraction of higher MM cellulose. This corroborates well



**Figure 7:** The MMD of cellulose in pulps cooked at an initial EA concentration at the start of the cooking stage of 0.6 M or 0.5 M. Pulps at KN approximately 30 and 40 were analysed. (a) Reference impregnation at 130°C for 30 min and initial EA in impregnation 1.3 M, (b) prolonged impregnation at 105°C for 120 min and initial EA in impregnation 1.3 M and (c) HAI at 105°C for 30 min and initial EA in impregnation 1.7 M.

with the viscosity distribution through wood chips proposed by Li et al. (2000). The cellulose molecules closer to the surface have been exposed to alkaline hydrolysis to

a greater extent and will subsequently be subjected more to secondary peeling, which explains the shift to a larger fraction of high MM cellulose.

An effect of impregnation conditions on yield was already indicated after impregnation (Brännvall and Reimann 2018). The amount of wood components dissolved during impregnation was significantly higher in the reference and prolonged impregnation cases, approximately 22% was already lost prior to cooking whereas impregnation with high alkali only dissolved 15% (Brännvall and Reimann 2018). Although HAI lead to a higher pulp yield at a given KN, it appears that more carbohydrates were lost during pulping as the 6%-unit yield advantage after impregnation decreased to only a 1%-unit yield increment after pulping. This implies that the pulping after high alkali impregnation needs to be modified in order to preserve more of the carbohydrates.

## Conclusions

Yield improvements by 1–1.5% units can be achieved by impregnation with a high initial EA concentration (HIEAC). The reference and prolonged impregnation led to the same yield level. The yield improvements by HIEAC seem to be due to a higher cellulose yield and possibly also higher glucomannan yield. Analysis of the MMD revealed a very similar distribution for all pulps obtained after HIEAC impregnation. The MMD between pulps obtained after prolonged impregnation showed a large variation depending on KN and alkali concentration at the beginning of cooking. Pulps obtained after reference impregnation also had a large MMD variation. It can be safely concluded that HIEAC impregnation leads to an even impregnation of the chips with sufficiently high alkali concentration. This helps avoid alkaline hydrolysis of cellulose close to the chip surfaces and thus reduces secondary peeling.

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