

## Oxygen Delignification of Acid Sulfite and Bisulfite Softwood Pulps

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This study discusses alternatives for the production of sulfite pulps cooked to high kappa numbers, and a subsequent oxygen treatment by using the same cation in the cooking and in the oxygen stages. Magnesium was used as a cation during both the cooking and oxygen delignification stages. By using the same cation in the cook and in oxygen delignification, it is theoretically possible to recover filtrates and send them to the chemical recovery system, meaning that the discharge of pollutants will be very low. Acid sulfite and bisulfite pulps at yields between 56 and 57% (kappa number between 50 and 55) were produced and then delignified with oxygen and magnesium hydroxide to a kappa number between 25 to 30. It was found that the delignification process time was shorter and the yield and viscosity increased, compared with delignification to the same kappa number (25 to 30) for a single cooking stage. The tear and tensile strengths were however unchanged, regardless of delignification process used.

*Keywords:* Acid sulfite cooking; Bisulfite cooking; Dynamic contact angle; Magnesium base; Oxygen delignification; Pulp strength; Pulp yield; Sodium borohydride

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### INTRODUCTION

The method of delignifying pulp with oxygen prior to bleaching has been thoroughly studied and developed since the late 1960s in the Soviet Union, France, and Sweden. It is now used in almost all pulp mills throughout the world that produce bleached kraft pulp. Parameters such as pulp consistency, delignification chemicals, and additives have been investigated in the past. Kinetic studies of oxygen delignification (Teder and Olm 1981; Agarwal *et al.* 1999) have given insight into the chemical behavior of the process. Pulp strength and beatability optimization studies of the O-stage have been performed by Poukka *et al.* (1999). Methods for protecting cellulose from degradation in a novel way using magnesium sulphate and phenol during delignification have also been reported (Chen and Lucia 2002).

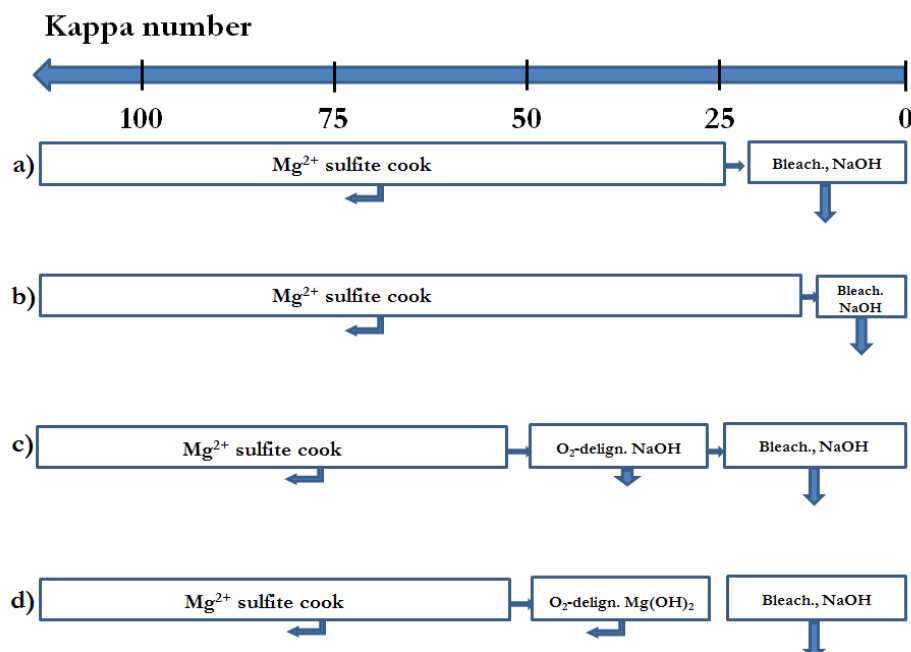
The O-stage has also been of interest to some sulfite pulp mills. Sodium sulfite pulps have been lab-delignified with a sodium hydroxide/oxygen (NaOH/O<sub>2</sub>) mixture by Christensen (1974a). Magnesium is a more common cooking base in sulfite pulp mills, and magnesite pulps have been delignified with oxygen and magnesium hydroxide (Mg(OH)<sub>2</sub>), as studied by Bokström and Tigerström (1991). Süss (1986) studied the usage of magnesium oxide (MgO) and peroxide in the O-stage and found that the lignin/carbohydrate selectivity could be increased under mild conditions. The main reason for using Mg(OH)<sub>2</sub> instead of NaOH was the possibility to recover the filtrate from the O-stage to the chemical recovery system of the pulp mill. Furthermore, the use of MgO in the

O-stage results in higher pulp yield compared to oxygen delignification with NaOH as the alkali source (Luo and Christensen 1992).  $Mg(OH)_2$  is a weak alkali but is capable of reducing the lignin content of sulfite pulps comparably to NaOH, although higher temperature must be used (Christensen 1975; Hruschka 1980). Calcium and ammonium hydroxide were also studied by Christensen (1974b). However, when the same delignification conditions were used, the use of calcium as the alkali in the O-stage resulted in inferior delignification rates compared to those achieved using sodium and magnesium hydroxide, whereas ammonium hydroxide had a slightly higher delignification rate than  $Mg(OH)_2$  (Christensen 1974b).

Although oxygen delignification is not currently used to any great extent in sulfite mills, some mills implemented such a process stage in the 1980s. Most of these mills used sodium as the cooking base, but some calcium-based mills implemented O-stages. An O-stage using  $Mg(OH)_2$  as the alkali was successfully implemented at the Kelheim magnesium sulfite pulp mill in Germany in the mid-1980s (Kovasin 1988).

From a pulp strength point of view, the optimum kappa number after the cooking stage for softwood sulfite paper pulps is between 25 and 30. This is the case for both the acid sulfite and the bisulfite processes (Rydholm 1965). However, sulfite mills usually cook the pulp to a lower kappa number due to environmental reasons, because the cooking liquor can be recycled but the bleaching filtrates usually cannot.

Patt *et al.* (2002a, 2002b, 2004) showed that it is possible to stop the cook at kappa numbers between 35 and 50 and produce fully bleached soft- and hardwood pulps with increased yield and strength properties. The introduction of an O-stage after the shortened cook likely does not negatively influence the yield and strength of the pulp. In a pulp mill, the filtrates from both the cook and the O-stage could then be incorporated into the chemical recovery system if the recovery boiler could handle the extra load. If NaOH were used as the alkali in the O-stage, the recycling of the filtrate would be very complex and uneconomical if pulping were done with magnesium sulfite. In Fig. 1, a summary of different sulfite cooking and oxygen delignification cases is shown.



**Fig. 1.** Different cooking and oxygen delignification alternatives in a magnesium sulfite pulp mill

The MgO/O<sub>2</sub> alternative, case “d”, is further described in Fig. 2. Case “a” shows a magnesium-based cook to kappa 23 to 25 followed by bleaching to full brightness with no bleaching filtrate recovery. In case “b” the pulp is cooked to kappa 15 and then fully bleached, and no bleaching filtrates are recovered. In case “c” the pulp is cooked to kappa 50, with the oxygen delignified using NaOH to roughly 25 kappa and fully bleached. The drawback in case “c” is that the sodium-based filtrate from the O-stage could not be recovered by the chemical recovery system of a magnesium-based pulp mill. Case “d” is similar to case “c” but uses Mg(OH)<sub>2</sub> as the alkali in the O-stage instead of NaOH, making it possible to recycle the O-stage chemicals to the brown stock wash and ultimately to the chemical recovery system.

Figure 2 shows two sulfite cooking alternatives in which the degree of delignification in the cook is the same. Due to the differences between the cooking processes, the bisulfite cook has to be carried out about 30 °C higher than the acid sulfite cook to keep the cooking time comparable between the processes.

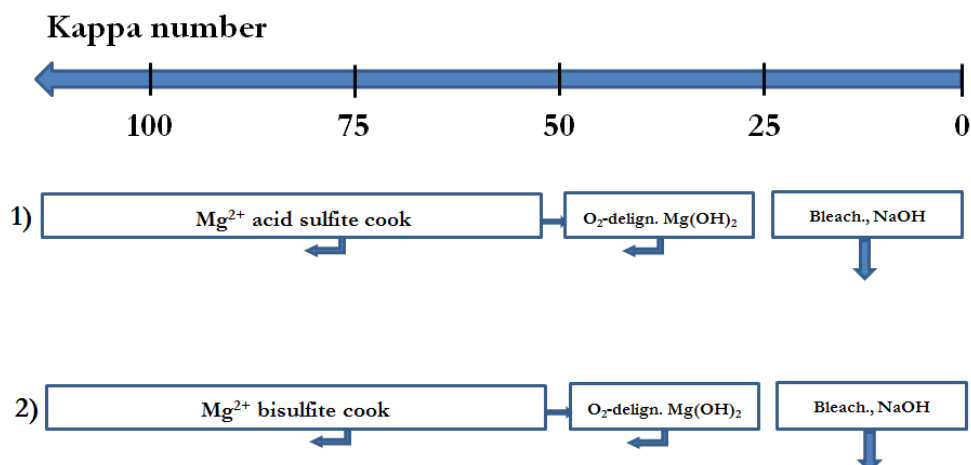


Fig. 2. MgO/O<sub>2</sub> delignification in either an acid sulfite (1) or a bisulfite (2) pulp mill

The aim of this study was to investigate the possibility of increasing the pulp yield and strength of unbleached magnesium-based sulfite pulps at kappa numbers between 25 and 30 by using an O-stage with Mg(OH)<sub>2</sub> as the alkali. Both acid sulfite and bisulfite pulping were included, and the results were used as a reference compared to cooking to the same kappa number *via* cooking only.

## EXPERIMENTAL

### Wood Material

All pulps were produced from spruce chips provided by Stora Enso, Skoghall, Sweden. Lab chip screening removed sawdust and pin chips. The screened chips (average length, 35 mm; width, 20 mm; thickness, 5 mm) were air-dried at room temperature to approximately 93% dryness. MgO (Puriss, VWR International, Sweden) was mixed with 5 L of distilled water, and then SO<sub>2</sub> gas (Puriss, AGA, Sweden) was added to the solution with a diffuser (Table 1). The solution was slowly stirred throughout the addition of the chemicals over the course of approximately 1.5 h. The cooking acid was then analyzed for total and combined SO<sub>2</sub> contents according to TAPPI method T 604 cm-09 (2009).

**Table 1.** Amount of MgO and SO<sub>2</sub> Added for Preparation of Cooking Liquors

	Acid sulfite	Bisulfite
MgO (g/ L)	6.3	15.6
SO <sub>2</sub> (g/ L)	60	50

### Cooking Procedures

250 g of dry wood chips (screened by hand for removal of knots, bark, and heavily damaged chips) were added to each autoclave (cylindrical steel vessels with 2.5-L volume), and the chips were then steamed for 15 min at roughly 2 bar. The cooking acid was then poured into the autoclaves which then were sealed and immersed in a heated glycol bath. The cooking parameters are shown in Table 2. When the cooking time was reached, the autoclaves were removed and cooled in a cold water bath. The pulps were then washed and disintegrated before they were stored overnight in buckets with distilled water. The next day, the pulps were thoroughly washed until neutral pH was reached. Screening with a slot width of 0.2 mm was then carried out.

**Table 2.** Cooking Parameters of the Two Types of Cooks

	Acid sulfite	Bisulfite
Liquor-to-Wood Ratio	4:1	4:1
Total SO <sub>2</sub> (kg/ptw <sup>*</sup> ; %)	240; 6	200; 5
Combined SO <sub>2</sub> (kg/ptw <sup>*</sup> ; %)	40; 1	100; 2.5
pH (25 °C)	1.3	4.0
Cooking Temperature (°C)	135	160
Cooking Time (h)	3 to 7	1 to 5

\* per ton wood

### Oxygen delignification

As MgO has very low solubility in water (0.086 g/L at 20 °C), the pH of a MgO/Mg(OH)<sub>2</sub>-water mixture is lower (around 11) than that of a NaOH-water mixture (around 13). This means that MgO-oxygen delignification had to be carried out at higher temperature than NaOH-oxygen delignification. Luo and Christensen (1992) showed that a temperature of 135 °C and a retention time of 90 min for O-stage delignification with magnesium as the base could reduce the lignin concentration of a sulfite pulp to the same level as in an NaOH-oxygen system at 105 °C with the same retention time. The MgO-oxygen delignification parameters used in this work were based on these findings.

Solid MgO (20 kg/ton pulp) was added to water (20 °C) and mixed to form a slurry. The magnesium slurry was then mixed with washed, screened pulp samples and the resulting mixtures were then put in autoclaves. The autoclaves were sealed and oxygen pressure was applied (6 bar). The pulp samples (pulp consistency, 10 wt%) were then heated to 130 °C and delignified for 1 to 2 h. The MgO-oxygen delignified pulp samples were analyzed for yield, viscosity, and kappa number.

### Preparation of Pulp for Strength Testing

#### Beating

The pulp samples used for tear and tensile strength testing were beaten in a PFI-mill to different °SR levels, as shown in Table 3. The aim was to produce pulps as equally beaten as possible with respect to °SR for each cooking process.

**Table 3.** °SR Values of the Pulps for the Different Cooking Processes

Cooking Process	°SR
Bisulfite	30 to 40
Acid Sulfite	50 to 60

*Sheet formation*

The beaten pulp samples were then made into sheets for strength testing in accordance with ISO standard 5269-1 (ISO 2005).

**Dynamic Contact Angle (DCA) Measurement**

DCA measurement was performed using a Radian DCA 322 contact angle analyzer (Cahn Instrument). The fibre samples were air-dried at ambient temperature to avoid hornification effects which would interfere with the DCA analysis. The analysis was performed according to the procedures described by Kvarnlöf (2007). At least six fibre samples were analyzed for every data point in the study. The force exerted on the fibre was related to the contact angle on the fibre surface by the Wilhelmy plate technique equation, Eq. 1, as follows, (Lodge and Bhushan 2006).

$$F = \gamma * P * \cos \theta + (W - \sigma * g * y * A) \quad (1)$$

In Eq. 1,  $F$  is the measured force,  $\gamma$  the surface tension of the wetting liquid (distilled water),  $P$  the wetted perimeter of the fibre at the liquid/air interface,  $\theta$  the contact angle on the fibre surface,  $W$  the weight of the fiber,  $\sigma$  the density of the wetting liquid,  $g$  the gravitational force,  $y$  the immersion depth of the fiber, and  $A$  the cross-sectional area of the fiber. Equation 1 can however be simplified to Eq. 2 in this case (Huang *et al.* 2006).

$$F = \gamma * P * \cos \theta \quad (2)$$

**Analysis Methods***Pulp yield*

The pulp yield was calculated on the basis of the bone-dry chip weight for all samples. The drying temperature was 105 °C.

*Sodium borohydride treatment*

10 g of dry pulp was mixed with distilled water to a pulp concentration of 10 wt%. 0.1 g of sodium borohydride (NaBH<sub>4</sub>) was added to the pulp slurry which then was placed in a plastic bag. The bag was sealed and put in a warm water bath (50 °C) for 1 h. The pulp was then washed with hot water to remove residual NaBH<sub>4</sub>. The procedure was done in accordance with US Patent 2898333 (1959).

*Viscosity*

The viscosity of the pulp samples were analysed according to ISO standard 5351 (ISO 2010).

*Kappa number*

The kappa number of the pulp samples was analysed according to ISO standard 302 (ISO 2004).

*Tear- and tensile index*

The tear and tensile index measurements were performed in accordance with ISO standards 1974 (ISO 2012) and 1924-2 (ISO 2008).

*Copper number*

The copper number analysis was performed in accordance with TAPPI-standard T 430 cm -09 (2009).

**RESULTS AND DISCUSSION**

The analysis parameters for the non-oxygen delignified- and oxygen-delignified pulps are shown in Tables 4 and 5.

**Table 4.** Analysis Parameters for the Acid Sulfite and Bisulfite Pulps (Non-Oxygen Delignified)

Pulp Type	K	Yield (%)	pH <sub>i</sub> <sub>n</sub>	pH <sub>o</sub> <sub>u</sub> <sub>t</sub>	Beating (°SR)	Tear Index (mN m <sup>2</sup> /g)	Tensile Index (kN m/kg)	Tear x Tensile	Copper Number
Acid Sulfite	47	55.8	1.3	1.3	52	5.9	84.2	497	2.0
Acid Sulfite	28	53.1	1.3	1.2	55	6.1	86.1	525	2.1
Acid Sulfite	20	51.1	1.3	1.2	65	5.1	72.7	371	-
Acid Sulfite	12	48.3	1.3	1.2	61	4.2	63.7	267	-
Bisulfite	57	57.5	4.0	3.5	38	7.3	102.0	745	1.6
Bisulfite	35	55.0	4.0	3.4	34	8.7	91.5	796	1.5
Bisulfite	26	53.9	4.0	3.3	33	9.2	85.7	788	-
Bisulfite	13	49.5	4.0	2.6	39	8.5	74.5	633	-

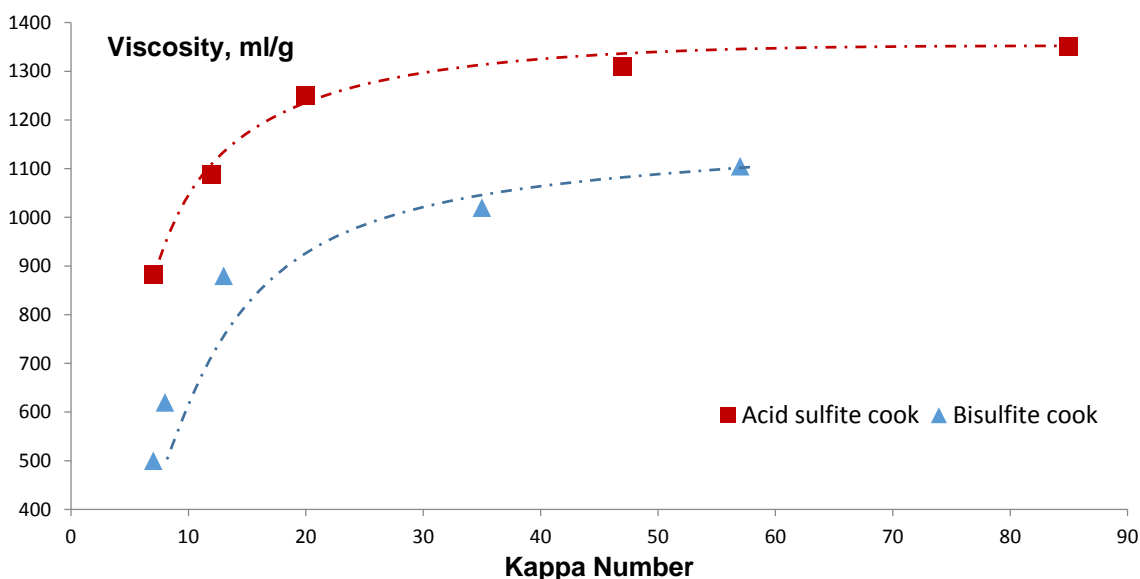
**Table 5.** Analysis Parameters for the Oxygen-Delignified Pulps

Pulp Type	K <sub>start</sub>	K <sub>end</sub>	Yield (%)	pH <sub>i</sub> <sub>n</sub>	pH <sub>o</sub> <sub>u</sub> <sub>t</sub>	Beating (°SR)	Tear Index (mN m <sup>2</sup> /g)	Tensile Index (kN m/kg)	Tear x Tensile	Copper Number
Acid Sulfite	47	28	54.5	11.0	9.5	55	6.0	85.2	511	2.1
Acid Sulfite	47	19	52.6	11.0	8.9	60	5.1	74.2	378	2.0
Bisulfite	57	36	56.8	11.0	9.7	31	9.6	81.4	781	2.0
Bisulfite	57	27	55.1	11.0	9.0	32	9.2	83.8	771	2.1

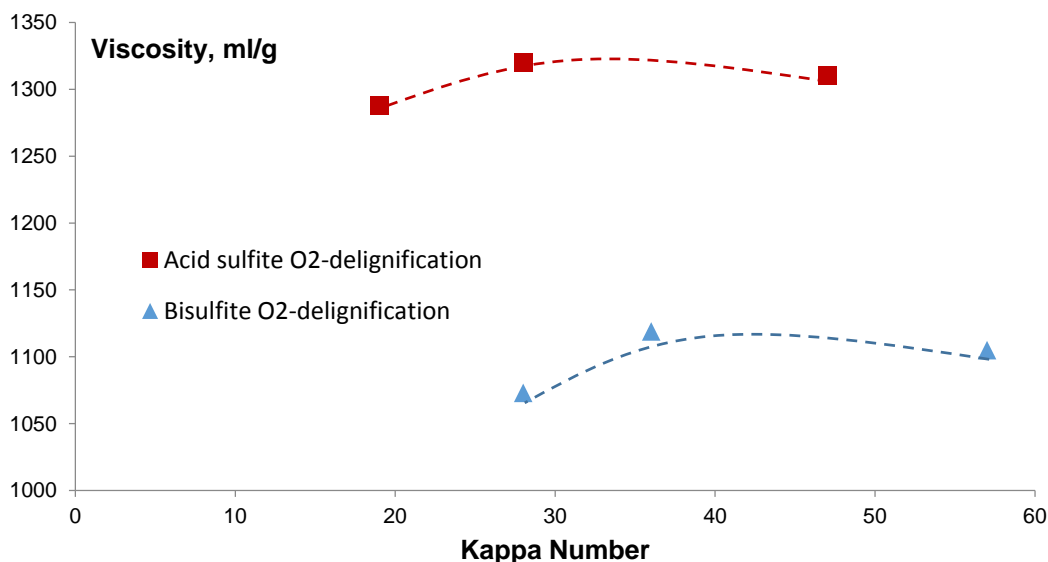
Figure 3 shows the viscosity of the bisulfite and acid sulfite pulps *versus* the kappa number. The higher viscosity in the acid sulfite pulp samples was most likely due to the rather high cooking temperature used (135 °C) for an acid sulfite cook, which increased carbohydrate degradation, mainly of hemicelluloses. The viscosity of the non-oxygen delignified pulps decreased steeply below kappa 20 for both cooking methods. Bisulfite cooks rapidly increase in acidity as the system is un-buffered and if the cook is prolonged too far. In this case, beyond 20 kappa, the cellulose molecules were heavily degraded. In the acid sulfite cook, the rapid decrease in viscosity depended on the decreasing

concentration of  $\text{HSO}_3^-$  ions in the cooking liquor, favoring the degradation of carbohydrates (Rydholm 1965).

As shown in Fig. 4, oxygen delignification of the 57 kappa sample for the bisulfite pulp exhibited good selectivity and viscosity, and the viscosity was maintained down to kappa numbers of 25 to 30. The viscosity of the acid sulfite pulp samples was also maintained throughout oxygen delignification from kappa 47 to the studied kappa interval of 25 to 30 at a higher level than in the bisulfite pulp. It was found that the oxygen-delignified pulp samples exhibited a similar correlation of viscosity as a function of kappa number as the non-oxygen delignified pulps, although at a slightly higher viscosity.



**Fig. 3.** The intrinsic viscosity after the cook *versus* the kappa number for the two sulfite pulping alternatives. All pulp samples were treated with  $\text{NaBH}_4$  prior to viscosity analysis. Each data point is based on an average of at least three cooks.



**Fig. 4.** The corresponding intrinsic viscosity after the  $\text{MgO}/\text{O}_2$  delignification stage *versus* the kappa number. All pulp samples were treated with  $\text{NaBH}_4$  prior to viscosity analysis.

Higher viscosity may have been achieved in this study because the viscosity measurements were performed on pulp samples that had been treated with NaBH<sub>4</sub>. Borohydride is known to reduce the carbonyl groups of the cellulose (US Patent 2898333 1959; Hartler and Sundberg 1960), thus stabilizing them and increasing the viscosity. Viscosity analyses were therefore performed both on untreated samples and on NaBH<sub>4</sub>-treated samples to examine if there was any viscosity difference between the samples. The viscosity difference between the oxygen-delignified pulp samples, treated with or without NaBH<sub>4</sub>, was significantly greater than the non-oxygen delignified pulp samples, as shown in Table 6. The oxygen-delignified pulps likely contained large amounts of carbonyl groups on their cellulose chains, which react easily with the copper complex of the solution used in the viscosity analysis test. This was indicated by the copper number analysis, which revealed significantly higher values for the oxygen-delignified samples, especially in the bisulfite pulps, as shown in Tables 4 and 5.

A difference in viscosity between the non-oxygen delignified pulp samples of the two cooking processes, when treated with NaBH<sub>4</sub>, was also found. The pulp samples of the acid sulfite process increased in viscosity by approximately 80 mL/g when treated with NaBH<sub>4</sub>, whereas the viscosity of the pulp samples of the bisulfite process was increased by much less (10 to 30 mL/g), as shown in Table 6. This indicated that the acid sulfite cooking process produced more carbonyl groups during the cook than the bisulfite process. This was also shown by the copper number analysis. A copper number analysis is defined as the amount of metallic copper, in grams, that is formed from the reduction of copper sulfate by 100 g of pulp fibers. A high copper number value indicates that the pulp contains a large amount of reducing agents, such as carbonyl groups. Carbonyl groups on the cellulose chains make the cellulose more susceptible to chain scission.

**Table 6.** Difference in Pulp Viscosity between Untreated Pulps and Pulps Treated with NaBH<sub>4</sub> at Different Kappa Numbers

Cooking Process	Sample	Kappa Number	Viscosity (mL/g) Untreated	Viscosity (mL/g) NaBH <sub>4</sub> -treated	Viscosity Difference (mL/g)
Bisulfite	non-oxygen delignified	50	1070	1100	30
Bisulfite	non-oxygen delignified	35	1010	1020	10
Bisulfite	oxygen-delignified	36	950	1120	170
Bisulfite	oxygen-delignified	27	870	1073	203
Acid Sulfite	non-oxygen delignified	47	1223	1310	87
Acid Sulfite	non-oxygen delignified	20	1179	1250	71
Acid Sulfite	oxygen-delignified	28	1182	1320	138
Acid Sulfite	oxygen-delignified	19	1156	1288	132

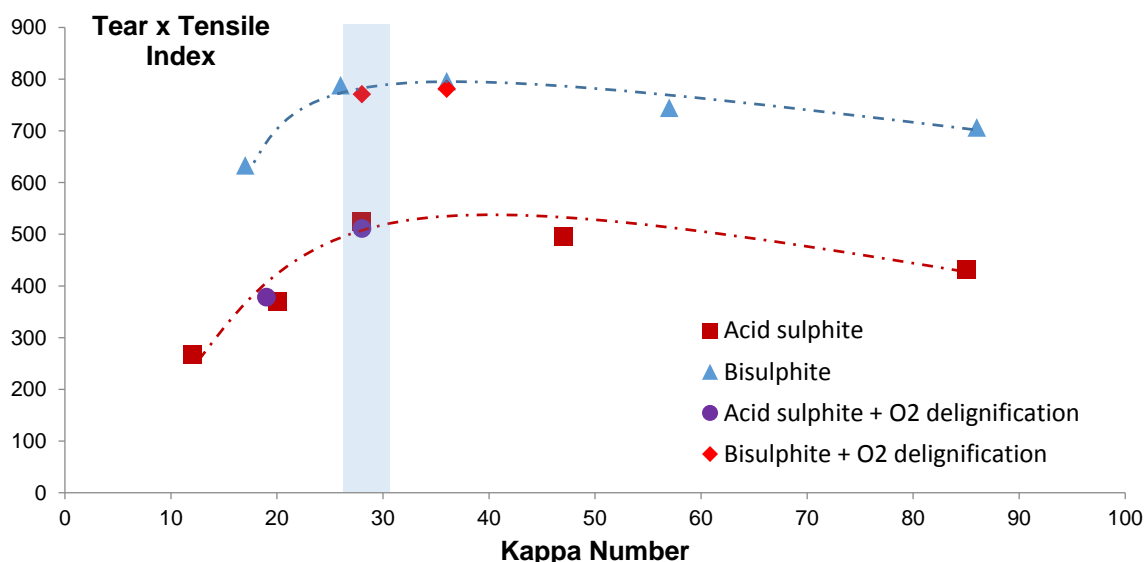
The non-oxygen delignified acid sulfite pulp contained a similar concentration of carbonyl groups as the oxygen treated pulp sample, as shown in Tables 4 and 5. However, after the oxygen stage, it was found that the viscosity differences between the NaBH<sub>4</sub>-treated and untreated bisulfite pulp samples were significantly greater than the viscosity differences between the acid sulfite pulp samples. This indicates that oxygen



delignification treatment of bisulfite-cooked pulp produces more carbonyl groups than oxygen-treatment of acid-sulfite cooked pulp. It also means that most of the carbonyl groups in the acid sulfite pulp were already formed in the cook and that the amount of additional carbonyl groups formed on the cellulose chains in the oxygen stage was small.

The usage of borohydride on sulfite pulp is not new. Ni *et al.* (1998) showed that addition of NaBH<sub>4</sub> in an O-stage using Mg(OH)<sub>2</sub> as the alkali could improve the yield, viscosity, and strength of the pulp. The study confirmed that oxygen-delignified pulps should be borohydride-treated prior to viscosity measurement to obtain more accurate results.

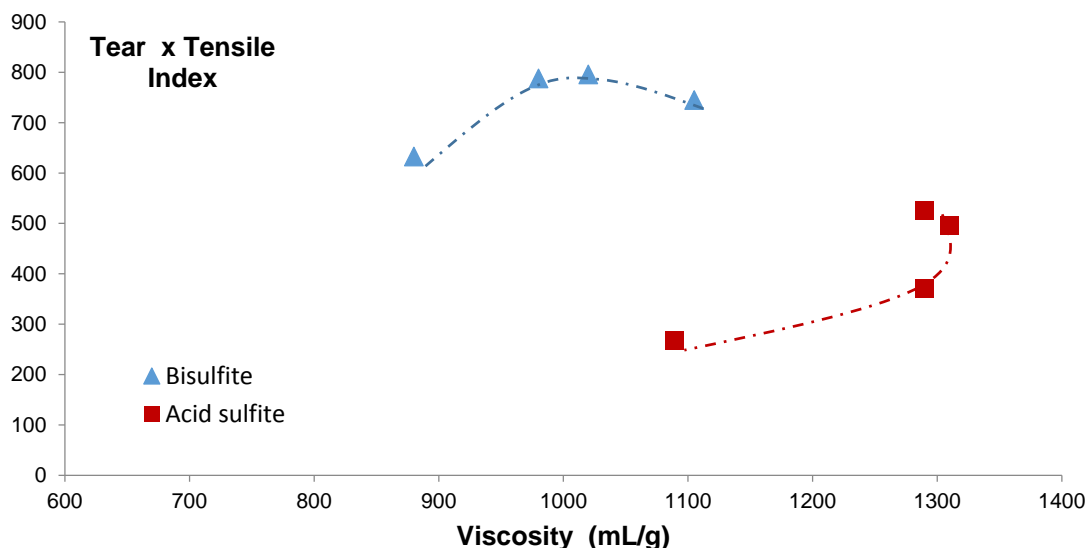
It was also important to investigate the physical properties of the pulp. Figure 5 shows a comparison between cooked, non-oxygen delignified pulp samples and cooked, oxygen-delignified pulp samples. The oxygen-delignified samples had roughly the same strength as the non-oxygen delignified pulps at the studied kappa interval for both cooking methods. However, the product of the tear and tensile indexes was significantly lower for the acid sulfite pulp than for the bisulfite pulp. This is in accordance with the literature. Annergren *et al.* (1963) indicated that bisulfite pulps, in general, are stronger than acid sulfite pulps. Although the viscosity was higher for the acid sulfite pulp than the bisulfite pulp, the acid sulfite pulp was significantly weaker. The mechanical strength of softwood sulfite pulp is influenced by the fiber length, and the strength of the bonds between fibers. The higher strength of the bisulfite pulp, shown in Fig. 5, was probably due to the higher hemicellulose yield and the higher fiber strength because the acid sulfite pulp fibers are weakened by the low-pH cook. This weakening was especially due to hydrolytic attack by the acid in the weakened zones caused by the chipper (Hartler and Sundberg 1960). Thus, the intrinsic viscosity cannot be used to forecast the final pulp strength, as shown in Fig. 6.



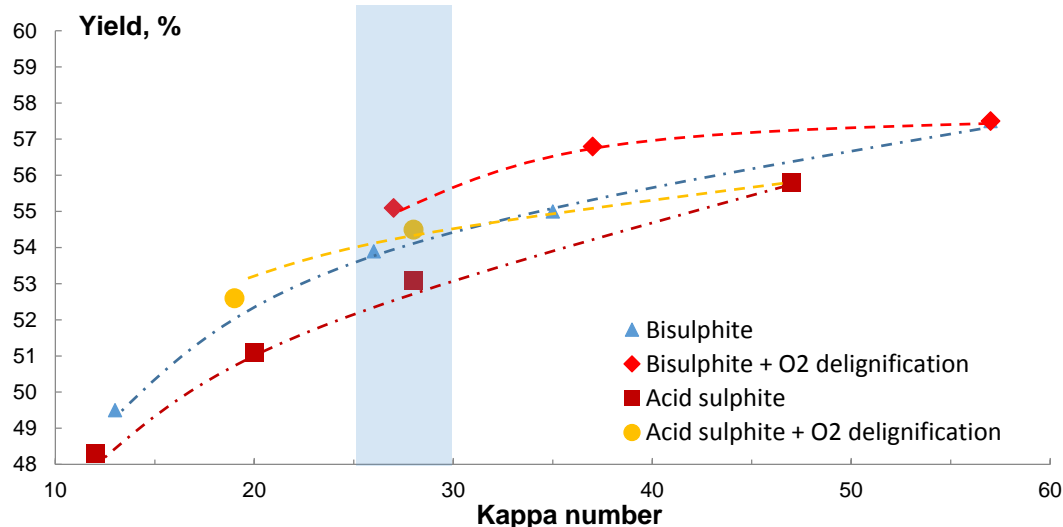
**Fig. 5.** Tear x Tensile index *versus* kappa number for bisulfite- and acid sulfite-cooked pulps. The highlighted area denotes the kappa number interval between 25 and 30.

Figure 7 shows the pulp yield at different kappa numbers for the bisulfite and acid sulfite pulping experiments with oxygen delignification. In the figure, the kappa number level between 45 and 60 was chosen as the starting point for oxygen treatment, and after the oxygen stage, it was found that the pulp yield was 1 to 1.5% higher within the studied

interval *versus* that of the non-oxygen delignified pulps of the bisulfite process. The yield of the oxygen-delignified acid sulfite pulps was roughly 1.5% higher than that of the non-oxygen delignified bisulfite pulps at kappa 25 to 30. The bisulfite pulp had a higher yield than the acid sulfite pulp because of its higher hemicellulose content. Thus, the higher temperature in the bisulfite cook (160 *versus* 135 °C) resulted in lower intrinsic viscosity, according to Fig. 3, and thus, in shorter cellulose chains. However, the total weight of the carbohydrates remaining in the fibers was still higher than in the acid sulfite cook.



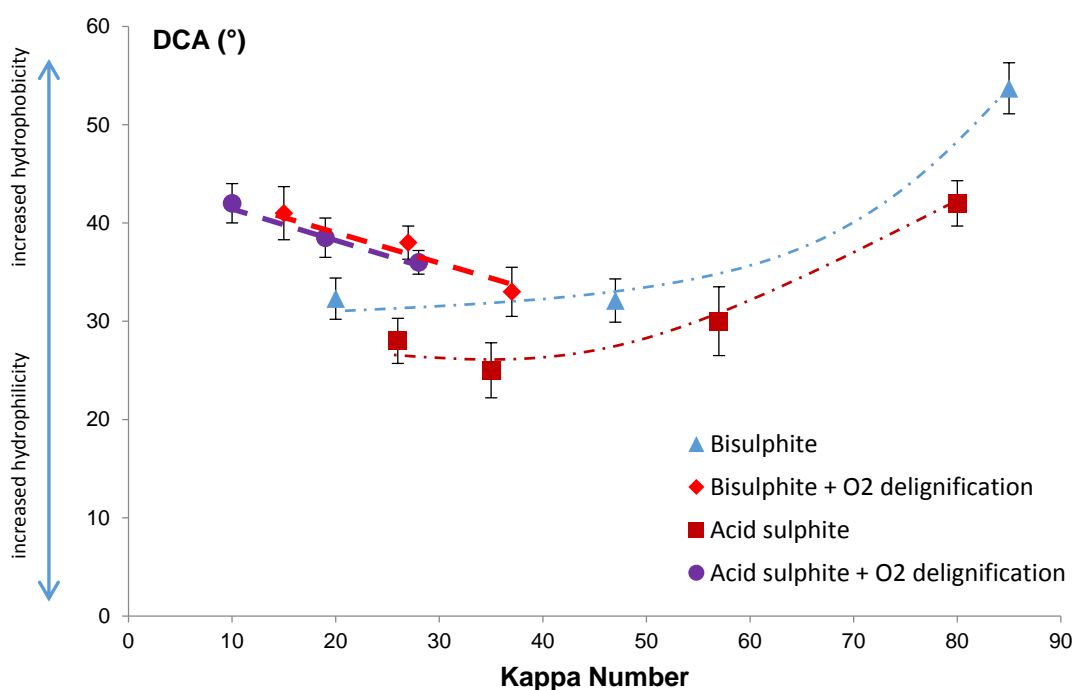
**Fig. 6.** The tear index times the tensile index *versus* the intrinsic viscosity for the two sulfite alternatives



**Fig. 7.** The pulp yield *versus* the kappa number for a bisulfite and an acid sulfite pulp with oxygen delignification. The highlighted area denotes the kappa number interval between 25 and 30. Each data point is based on an average of at least three cooks.

To investigate whether or not the discussed differences between the cooking processes could depend on the physical properties of the wood fibres, a dynamic contact angle (DCA) study was performed. The hypothesis was that a high contact angle indicated

relatively high hydrophobicity of the fibre surface (*i.e.*, the surface was rather smooth with a small amount of cracks and crevices, and the fiber charge was low). A low contact angle would show that the fibre surface was more ruptured, likely more susceptible to the diffusion of the cooking chemicals, and more charged. The hypothesis also suggested that the transfer of components, including lignin, hemicellulose, and cellulose, out of the fibre would be facilitated if the surface was disrupted, showing a low DCA. Figure 8 shows that the DCA of the acid sulfite fibres was lower than that of the bisulfite fibres. This is in accordance with the hypothesis discussed above, where low DCA indicates a more open structure of the fibre surface and the wood components more easily diffuse out of the fibre. The DCAs for the oxygen-delignified fibres, however, increased with decreasing kappa number, and it seemed that the hydrophobicity of the fiber surfaces increased with prolonged oxygen delignification following both cooking processes. This could be because the amount of free phenolic hydroxyl groups of the residual lignin in the pulp was reduced by prolonged oxygen delignification, in accordance with the conclusions of Gellerstedt *et al.* (1986). As the free phenolic hydroxyl groups of lignin ionize in alkaline media and phenolic radicals are formed in the presence of oxygen, lignin is fragmented and thus rendered more hydrophilic (Dence and Reeve 1996). A lower amount of free phenolic hydroxyl groups made the residual lignin in the pulp more hydrophobic, and thus the DCA increased with prolonged oxygen delignification.



**Fig. 8.** The dynamic contact angle (DCA) of individual pulp fibers measured after the cook and after the following oxygen stage for the two types of sulfite pulps studied. The error bars indicate the standard deviation of DCA-measurements of at least six samples per observation point.

Table 7 presents a comparison between the two cooking processes with and without oxygen treatment. The parameters were compared at kappa numbers in the interval between 25 and 30. It was found that the yield after the oxygen-delignification for the bisulfite pulp

was approximately 2 to 3.5% and the viscosity gain was 100 mL/g. The acid sulfite cook yield increased by 3 to 4% and the viscosity increased by approximately 50 mL/g.

**Table 7.** Yield and Viscosity Comparison at Kappa Number Interval Between 25 and 30 for the Different Cooking Processes Used

	Bisulfite	After O <sub>2</sub> - Treatment (Bisulfite)	Acid Sulfite	After O <sub>2</sub> - Treatment (Acid Sulfite)
Yield (%)	52 to 53	55 to 55.5	50 to 51	54
Viscosity (mL/g)	1000	1100	1250	1300
Tear x Tensile Index	Around 800	Around 800	Around 500	Around 500

## CONCLUSIONS

1. For both acid sulfite- and bisulfite pulps cooked to high kappa numbers (50-55) and further oxygen-delignified with Mg(OH)<sub>2</sub> to kappa numbers between 25 and 30, the yield and intrinsic viscosity were better than in pulps prepared *via* prolonged cooking without oxygen delignification to kappa numbers between 25 and 30.
2. A correlation between the DCA and the kappa number of both sulfite pulps was seen in this study, and the correlation was explained as due to the amount of charged groups of the fibers.
3. The experiments showed that the bisulfite process is preferred over the acid sulfite process as it produces pulps of higher strength and greater yield.

## ACKNOWLEDGMENTS

The authors wish to thank the Knowledge Foundation (KK-Stiftelsen) for their financial support of this study.

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Article submitted: February 10, 2015; Peer review completed: April 26, 2015; Revised version received and accepted: May 4, 2015; Accepted: May 7, 2015; Published: May 12, 2015.

DOI: 10.15376/biores.10.3.3934-3947