Extending delignification with AQ/polysulfide

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ABSTRACT: The kappa number of fibers entering the bleach plant must be lowered to meet the requirements of the Environmental Protection Agency's Cluster Rule. The options proposed for decreasing the kappa number include using oxygen delignification and/or extended digester delignification. Extended digester delignification can be implemented by modifying the cooking process (EMCC, RDH SuperBatch, or EnerBatch) or by using chemical additives [anthraquinone (AQ) or polysulfide (PS)]. Even though oxygen bleaching and modified cooking are proven technologies that can decrease the kappa number to the bleach plant, these two options require large capital investments, and the load to the recovery boiler is increased. The use of chemical additives AQ and PS is a low-capital-investment option for decreasing the kappa number and minimizing the impact on the recovery boiler. Additionally, a higher bleached pulp yield is possible.

KEYWORDS: Alkaline pulps, anthraquinone, bleachability, brightness, chemical properties, chemical pulps, chemical reactions, delignification, kappa number, ketones, kraft pulping, mechanical properties, modified kraft process, optical properties, permanganate number, polysulfide pulps, properties, pulp properties, quinones, yield.

The kappa number of fibers entering the bleach plant must be lowered to meet the Environmental Protection Agency's (EPA's) new Cluster Rule. This kappa number reduction must be implemented with a minimal change in the pulp properties. The recommended options for decreasing the kappa number have included using oxygen delignification and/or extended digester delignification. Oxygen is a proven technology that can decrease the kappa number entering the bleach plant. When the normal kraft cook is extended beyond kappa no. 30 without process modifications, the yield and strength properties of the pulp are significantly reduced because of lower selectivity of delignification. If the cooking process can be modified by implementing one of the modified cooking processes, lower kappa numbers can be achieved with improved strength properties. Using either oxygen bleaching or modified cooking, the kappa number to the bleach plant can be decreased by 50% compared to the conventional kappa no. 30 entering the bleaching process. The major disadvantages of these two options are the large capital investment required and the increase in the recovery boiler load. This load increase will be particularly undesirable in light of future requirements for bleach plant closure.

The use of polysulfide (PS) and anthraquinone (AQ) is another alternative for decreasing the kappa number *(1–7)*. PS stabilizes the carbohydrates by oxidizing the reducing end groups, resulting in an increased yield. PS does not affect the delignification rate significantly. AQ/AHQ reacts with both the reducing end groups of the carbohydrates and with the lignin. As a result, AQ/AHQ improves both yield (stabilization of the carbohydrates) and delignification. It is expected

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that PS and/or AQ can be used to delignify to a lower kappa number without affecting the strength properties.

PS/AQ can be used for the following purposes:

- Decreasing the kappa number at the same pulping conditions
- Decreasing the kappa number at a constant yield compared to kappa no. 30
- Increasing the pulping yield at kappa no. 30 to counter the higher recovery load to the boilers due to oxygen delignification.

This study was done to identify the potential of PS/AQ to pulp to a lower kappa number and to study the bleachability and strength of the pulps produced. The effects of PS and AQ were studied individually and in combination for extended pulping to kappa no. 20.

Experimental

Southern pine chips with 45% moisture from the coastal region of North Carolina were used for the study. In the preliminary lab work, the benefit of polysulfide was small if the chips were previously air dried. The AQ used was a dispersion provided by Westvaco. The polysulfide was prepared by dissolving elemental sulfur in sodium sulfide. Solutions of sodium sulfur, polysulfide, and sodium hydroxide were then mixed to simulate the polysulfide liquor that would be produced at the mill by the oxidation process. The cooks were done using the conditions shown in **Table I.**

The kraft pulps prepared using different charges of polysulfide and anthraquinone were used to study the effects of kraft cooking conditions on kappa number and yield. The pulps were bleached using the OD(EOP)D sequence, and the bleaching conditions are given in **Table II.** The final D stage was done at three chemical charges to achieve an 87% ISO brightness in the OD(EOP)D sequence. After every bleaching stage, the kappa number, viscosity, and brightness were determined. Kappa number and viscosity were evaluated using TAPPI Test Methods. The brightness was measured using an Elrepho-mat data color brightness tester.

The strength properties of the bleached pulps were evaluated at five freeness levels. Pulps were refined in the PFI mill at 0, 2000, 4000, 6000, 7000, and 8000 revolutions, and the freeness of the resulting pulps was measured. Handsheets were made according to TAPPI T 205 om-88. The sheets were then conditioned and tested for strength properties using TAPPI Test Methods.

I. Experimental cooks

Alkali charge:	19% for kraft, 30% sulfidity 19% for AQ, 30% sulfidity 20% for PS, 16.5% sulfidity 20% for PS/AQ, 16.5% sulfidity
H factor:	Varied using temperature at constant time: 45 min to temperature 115 min at temperature
Liquor/wood:	4/1

II. Bleaching conditions

	Bleaching sequence			
Parameters	O	D	EOP	D
Consistency, %	10	10	10	10
Chemical, %	2.5	Kappa fact. 0.22	-	0.5–1.6
Temperature, °C	100	50	75	70
Time, min	60	60	60	180
Final pH	11.5–12.0	3.5–4.0	11.0–11.5	3.5–4.0
Equipment	Quantum mixture	Bags	Autoclave	Bags

III. Liquor concentration examples

Component	*White liquor*	*Orange liquor*
Sodium hydroxide, g/L (as Na_2O)	72	89
Sodium sulfide, g/L (as Na_2O)	34	13
Sulfidity, %	32	12
Polysulfide, g/L S	0	7.5

IV. Pulping results of kraft, kraft-AQ, and kraft AQ-PS pulps*

Pulp	*Temp., °F/°C*	*Kappa no.*	*Total yield, %*	*Screened yield, %*	*Rejects, % on pulp*	*Rejects, % on wood*	*H factor*	*Sulfidity, %*	*AA, %*
Kraft	330/166	36.5	45.2	44.3	2.11	0.95	1311	30	19
	334/168	30.6	45.7	44.3	3.18	1.46	1586	30	19
	334/168	29.8	45.6	44.3	2.74	1.25	1586	30	19
	338/170	29.0	44.7	43.6	2.42	1.08	1900	30	19
	338/170	25.9	44.3	43.4	2.00	0.88	1900	30	19
	338/170	24.7	43.3	42.3	2.34	1.01	1900	30	19
	342/172	24.1	43.6	42.7	2.01	0.87	2210	30	19
	346/174	22.0	42.6	41.7	2.02	0.86	2636	30	19
Kraft	330/166	30.4	46.3	44.6	3.69	1.71	1311	30	19
AQ	338/170	22.7	44.0	42.9	2.44	1.07	1900	30	19
	346/174	22.1	44.0	43.1	2.22	0.98	2636	30	19
	346/174	19.6	43.0	42.2	1.80	0.78	2636	30	19
1.0 PS	330/166	37.9	46.7	44.4	4.95	2.32	1311	12	20
	338/170	28.7	45.2	44.3	1.96	0.89	1900	12	20
	346/175	21.7	43.6	43.1	1.09	0.48	2636	12	20
1.3 PS	330/166	36.2	48.2	47.1	2.45	1.18	1311	16.5	20
	338/170	25.5	45.8	44.7	2.23	1.02	1900	16.5	20
	346/174	21.4	43.9	43.1	1.84	0.81	2636	16.5	20
	346/174	20.5	43.8	43.0	1.77	0.77	2636	16.5	20
1.6 PS	330/166	31.7	48.2	46.3	3.93	1.89	1311	20	20
	338/170	24.0	46.7	45.4	2.63	1.23	1900	20	20
	346/174	21.5	44.8	43.6	2.54	1.14	2636	20	20
1.0 PS	330/166	28.0	47.3	46.5	1.53	0.72	1311	12	20
AQ	338/170	23.5	45.8	43.4	5.20	2.38	1900	12	20
	346/174	20.6	44.0	42.5	3.47	1.53	2636	12	20
1.3 PS	328/165	30.1	47.7	46.5	2.40	1.20	1195	16.5	20
AQ	328/165	28.7	47.7	46.4	2.73	1.30	1195	16.5	20
	330/166	28.3	47.7	46.5	2.40	1.15	1311	16.5	20
	338/170	21.2	45.7	45.0	1.41	0.64	1900	16.5	20
	346/174	19.4	44.8	44.1	1.46	0.65	2636	16.5	20
	346/174	18.9	43.4	42.8	1.25	0.54	2636	16.5	20
	346/174	18.8	43.7	43.2	1.16	0.51	2636	16.5	20
1.6 PS	330/166	29.4	48.9	47.5	2.81	1.37	1311	20	20
AQ	338/170	22.3	45.9	45.3	1.38	0.64	1900	20	20
	338/170	21.6	46.5	44.8	3.63	1.69	1900	20	20
	346/174	19.9	44.5	43.6	2.02	0.90	2636	20	20

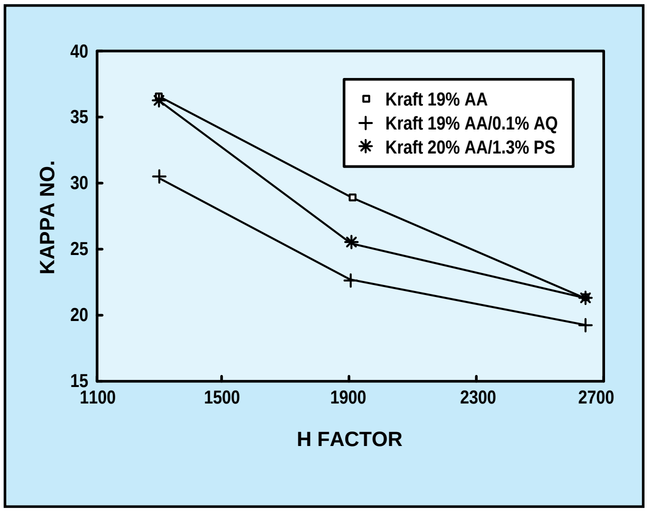
*All cooks 45 min to temperature; total cooking time of approximately 160 min. The indicated H factor is exact. All polysulfide cooks were 20% AA, but kraft and kraft-AQ cooks were 19% AA. AQ use is 0.1%.

Use of polysulfide in pulping

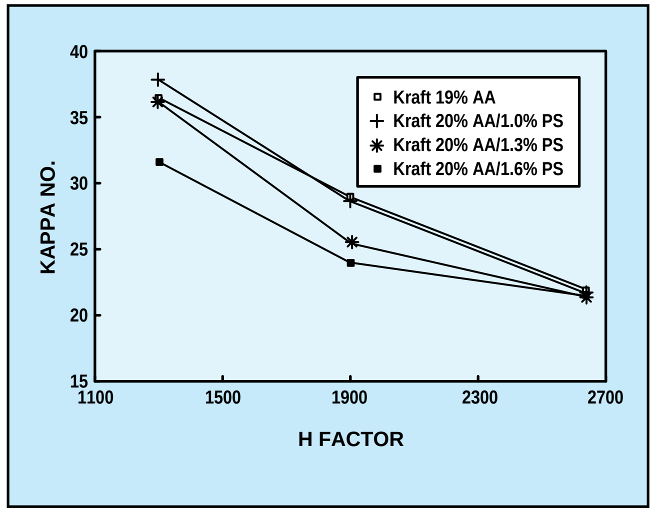
Polysulfide (Na_2S_x) at a mill will be produced by reacting the filtered white liquor with air. Some of the sodium sulfide in the white liquor will be converted to Na_2S_x. The concentration of Na_2S_x will be determined by the amount of the sodium sulfide in the white liquor (% sulfidity) and the oxidation process (MOXY, Chiyoda) used. An example of the liquor concentrations that can be expected is shown in **Table III.**

The % PS that can be applied on wood is not an independent variable. It is determined by the polysulfide concentration in the liquor, which is further controlled by the original sulfidity of the white liquor and the specific oxidation process used. For the example shown in Table III, the % PS on wood that can be charged is 1.47% on wood for a 20% AA charge. If higher dosages of polysulfide are required, the sulfidity of the kraft white liquor must be increased, or the polysulfide must be generated at

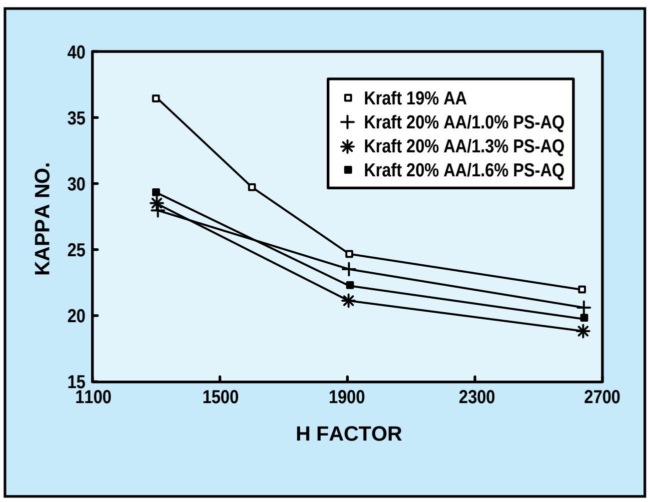
1. Relationship between H-factor and kappa number of kraft and PS/AQ pulps



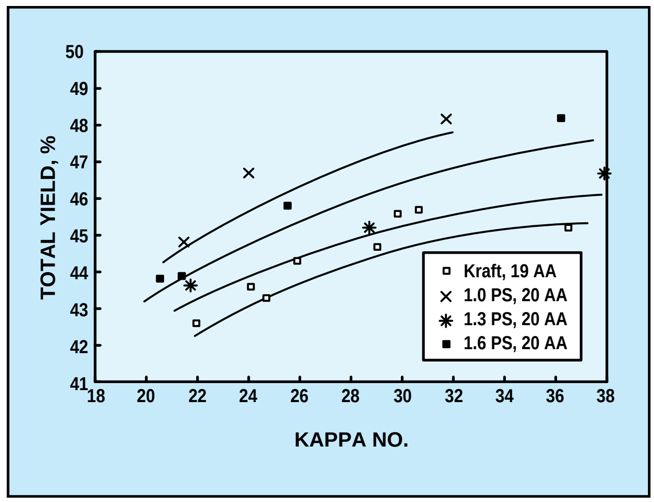
2. Relationship between H-factor and kappa number of kraft PS pulps



3. Relationship between H-factor and kappa number of kraft PS/AQ pulps



4. Kraft pulping as a function of PS without AQ

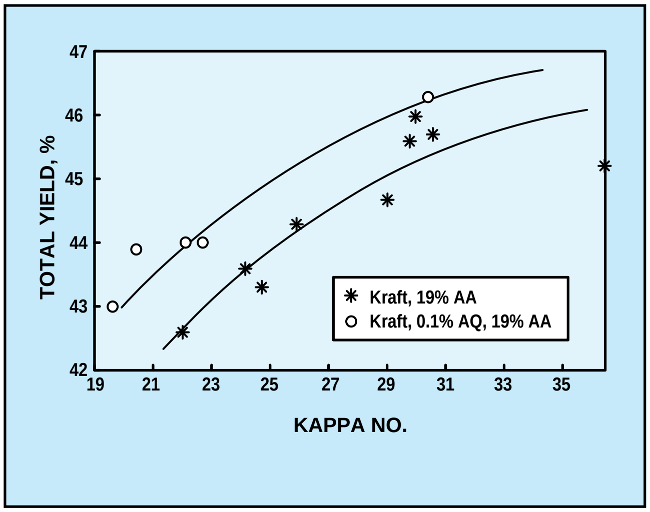


higher concentrations. In this study, the % PS on wood was varied from 1 to 1.6%. The sulfidity of the orange liquor (OL) to the digester is lower than that of the white liquor (WL) (32% for WL vs. 12% for OL). As a result, if the same % AA is used for PS (as for conventional cooking), the kappa number is higher. In this pulping study, the % AA was raised from 19 to 20% for the PS and PS/AQ pulping to keep the kappa numbers comparable at the same H factor as the conventional cooks. In this study, the sulfidity of the WL was 30% and that of the OL was 16.5%.

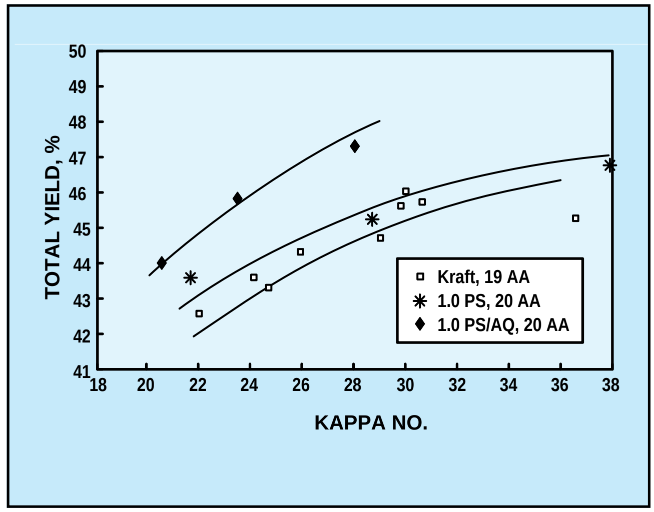
V. Kappa number for various options at the same H factor

Conditions	*% AA*	*H factor*	*Kappa no.*
Kraft	19	1800	29
Kraft, 0.1% AQ	19	1800	24
Kraft, 1% PS	20	1800	30
Kraft, 1.3% PS	20	1800	29
Kraft, 1.6% PS	20	1800	25
Kraft, 0.1% AQ, 1% PS	20	1800	24
Kraft, 0.1% AQ, 1.3% PS	20	1800	22
Kraft, 0.1% AQ, 1.6% PS	20	1800	23

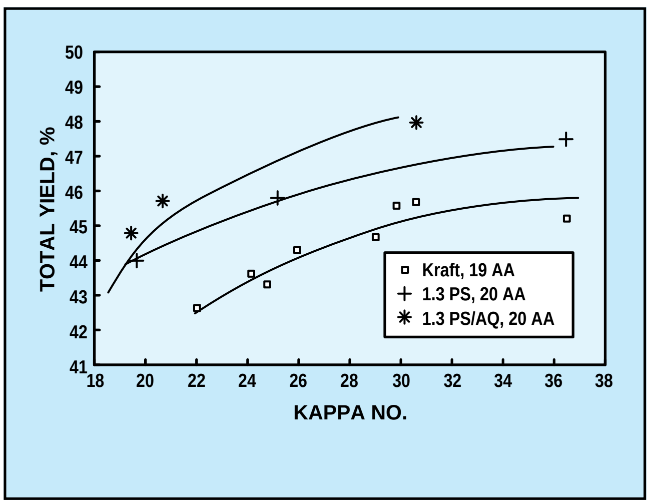
5. Kraft pulping with only 0.1% AQ on wood



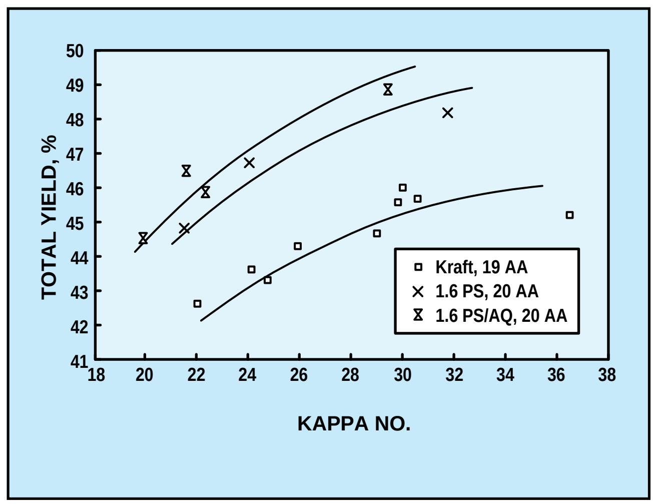
6. Kraft pulping at 1.0% PS on wood



7. Kraft pulping at 1.3% PS on wood



8. Kraft pulping at 1.6% PS on wood



VI. Minimum kappa number possible with various alternatives at the same yield as kappa no. 30 kraft

Process option	*Minimum kappa no.*
Kraft	30
Kraft, 0.1% AQ	26
Kraft, 1% PS	26
Kraft, 1.3% PS	24
Kraft, 1.6% PS	21
Kraft, 0.1% AQ, 1% PS	22
Kraft, 0.1% AQ, 1.3% PS	20
Kraft, 0.1% AQ, 1.6% PS	20

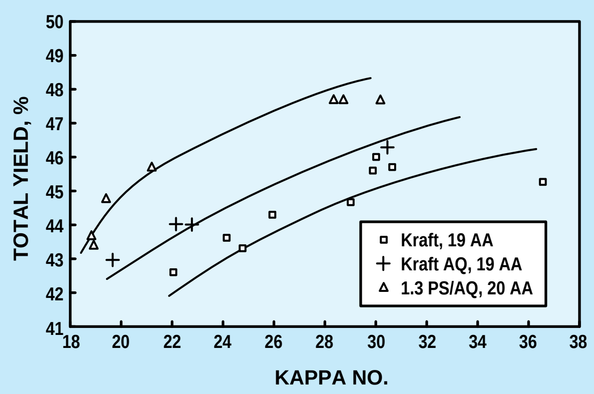
Results and discussion

Pulping results

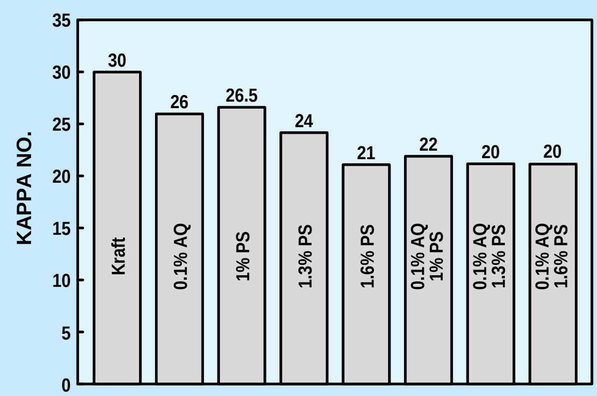
Pulps of various kappa numbers were produced by conventional kraft, kraft-PS, kraft-AQ, and kraft-PS/AQ. The kappa number, total yield, screen yield, and rejects are shown in **Table IV. Figure 1** shows the relationship between H factor and kappa number for the kraft cook and for the cooks using AQ or PS. Lower kappa numbers can be achieved by using 0.1% AQ at the same H factor. At an H factor of 1800, the conventional kraft resulted in kappa no. 29, while the kraft/AQ yielded kappa no. 24. If 1.3% PS is used, the kappa numbers are comparable to those from the kraft cooking, even though the % AA used for the PS pulping was higher. **Figure 2** shows the effect of PS charge on pulping. Slightly lower kappa numbers were achieved with increasing PS charge. The kappa number achieved for combinations of AQ/PS are shown in **Fig. 3.** The use of PS in combination with AQ resulted in kappa numbers comparable to the use of AQ only.

The kappa numbers that can be achieved for the pulping conditions

9. Kraft pulping at 1.3% PS/0.1% AQ



10. Various options to achieve minimum kappa numbers without changing the yield



used (% AA) for an H factor of 1800 are summarized in **Table V.** It is possible to decrease the kappa number by approximately 15% at the same H factor and % AA using AQ. The kappa numbers for PS pulping are the same as for conventional kraft if the % AA is increased from 19 to 20%. If low kappa numbers are desired with PS pulping, the H factor and/or % AA must be increased. If AQ and PS are used in combination, a 15% decrease in kappa number is possible at the same H factor, but the % AA must be increased from 19 to 20%.

Yield results

Polysulfide pulping. The yield vs. kappa relationship for the kraft cooks and the polysulfide cooks are shown in **Fig. 4.** The kraft cooks were done at 19% AA charge. The AA charge was increased to 20% AA for the polysulfide cooks, since the sulfidity of the polysulfide liquor was 16% as compared to 30% for the kraft cook. The use of 1% polysulfide on wood gives less than a 1% yield increase. At 1.3 and 1.6% polysulfide on wood, the yields are significantly higher. The benefits are diminished somewhat beyond 1.3% PS on wood. The amount of PS that can be charged will be determined by the WL sulfidity and the efficiency of the oxidation process.

Anthraquinone pulping. A 1% yield increase is achieved using 0.1% AQ, as shown in **Fig. 5.** This increase is lower in comparison to the work done previously at NC State *(3)*, possibly due to the slightly higher sulfidity used in this study.

Polysulfide/anthraquinone pulping. The results of using 0.1% AQ with the 1, 1.3, and 1.6% polysulfide are summarized in **Figs. 6–9.** With 1.3 and 1.6% polysulfide, the effect on yield appears to be additive. A net yield increase of 3% was measured with 1.3% PS/AQ, and an increase of 4% was seen with 1.6% PS/AQ. The trends indicate that the yield increase may be slightly lower as the kappa number decreases. The results for 1% PS/AQ show a yield effect that is more than additive, especially at kappa numbers greater than 24. The yield increase at kappa no. 28 is approximately 2.5% greater than the kraft case (44.6 vs. 47.3%).

These yield increases can be used to produce more pulp, to decrease the load to the boiler, or to decrease the kappa number to the bleach plant without changing the yield as com-

VII. Pulps evaluated for bleaching

Pulp type	*Kappa no.*
Kraft	30
PS 1%/AQ 0.1%	30
Kraft	24
PS 1.3%	20
AQ 0.1%	20
PS 1%/AQ 0.1%	21
PS 1.3%/AQ 0.1%	20

VIII. Bleaching summary of PS/AQ pulps

Sample	*Treatment*	*Kappa no.*	*Viscosity*	*Brightness*	*% ClO_2*	*% NaOH*
Kraft 30	Blank	30.08	36.32	25.15	-	-
	Oxygen	16.61	25.68	30.73	-	2.5
	D1	7.06	25.24	49.26	1.24%	-
	EOP	1.8 (PN)*	19.67	72.43	-	1.5
	D2	-	17.79	87% ISO	0.90%	0.4
	Total D	-	-	-	2.14%	-
Kraft 30	Blank	28.65	38.21	25.65	-	-
1.3 PS/0.1 AQ	Oxygen	15.67	28.71	31.7	-	2.5
	D1	7	24.21	52.42	1.32%	0.4
	EOP	2.1 (PN)	22.71	71.31	-	2
	D2	-	17.34	87% ISO	1.70%	0.6
	Total D	-	-	-	3.02%	-
Kraft 20	Blank	24	21.04	25.93	-	-
	Oxygen	10.9	15.13	34.15	-	2.5
	D1	4.67	13.41	60.81	0.91%	0.25
	EOP	1.6	12.4	79.26	-	1.5
	D2	-	9.96	87% ISO	0.50%	0.2
	Total D	-	-	-	1.41%	-
Kraft 20	Blank	19.8	20.34	26.93	-	-
1.3 PS	Oxygen	10.59	15.02	33.45	-	2.5
	D1	4.17	14.34	57.05	0.89%	0.3
	EOP	1.2 (PN)	13.22	76.07	-	1.5
	D2	-	11.52	87% ISO	0.65%	0.3
	Total D	-	-	-	1.51%	-
AQ 20	Blank	20.32	20.55	26.93	-	-
	Oxygen	10.34	14.05	33.44	-	2.5
	D1	4.52	14.34	53.58	0.87%	-
	EOP	1.48 (PN)	12.64	74.61	-	2
	D2	-	12.3	87% ISO	0.75%	0.4
	Total D	-	-	-	1.60%	-
Kraft 20	Blank	19.94	20.02	25.83	-	-
1.3 PS/0.1 AQ	Oxygen	9.98	14	33.39	-	2.5
	D1	4.09	15	60.48	0.84%	0.25
	EOP	1.2 (PN)	12.82	77.22	-	1.5
	D2	-	10.83	87% ISO	0.50%	0.3
	Total D	-	-	-	1.34%	-
Kraft 20	Blank	20.84	15.66	27.54	-	-
1.0 PS/0.1 AQ	Oxygen	10.22	12.18	34.58	-	2.5
	D1	4.23	11.09	60.63	0.85%	0.3
	EOP	1.2	10.54	78.87	-	1.5
	D2	-	9.12	87% ISO	0.60%	0.25
	Total D	-	-	-	1.45%	-

*(PN)=Permanganate no.

pared to kappa no. 30. The minimum kappa numbers that can be achieved without changing the yield (as compared to kappa no. 30) for the various options are summarized in **Table VI** and **Fig. 10.**

The pulping studies show that the kappa number can be decreased by 15% at the same conditions by using AQ. If PS is used individually, no significant decrease in kappa number was measured even when the % AA use was increased from 19 to 20%. If PS and AQ are used in combination, the decrease in kappa number was 15%, but the alkali use required an increase from 19 to 20%. If lower kappa numbers are desired for PS and PS/AQ, higher alkali and/or H factors will be necessary. A significant increase in yield was measured by using AQ, PS, or AQ/PS. With 1.3% PS and 0.1% AQ, kappa numbers as low as 20 can be achieved without affecting the yield as compared to kappa no. 30 conventional kraft.

IX. Strength properties of bleached kraft, kraft-AQ, and kraft PS/AQ pulps

Pulp	*Unbleached kappa no.*	*PFI rev.*	*Freeness (CSF), mL*	*Tensile index, N·m/g*	*Burst index, kPa·m²/g*	*Tear index, mN·m²/g*
Kraft 30	30.08	0	737	23.38	1.50	22.41
	30.08	2000	667	63.70	5.16	14.48
	30.08	4000	568	67.50	5.80	11.35
	30.08	6000	428	67.90	5.61	11.46
	30.08	8000	337	71.66	6.32	10.66
Kraft 30	28.65	0	739	28.23	1.80	24.43
1.3 PS/0.1 AQ	28.65	2000	637	67.78	5.30	12.41
	28.65	4000	492	72.49	5.90	9.93
	28.65	6000	332	72.42	6.43	9.90
	28.65	8000	238	69.88	6.50	9.25
Kraft 20	20	0	738	25.16	1.65	20.93
	20	2000	658	61.76	4.79	12.80
	20	4000	518	65.14	5.29	12.17
	20	6000	381	69.31	5.98	10.83
	20	8000	275	70.05	6.01	9.72
Kraft 20	19.8	0	724	23.44	1.61	22.81
1.3 PS	19.8	2000	641	62.82	5.42	12.46
	19.8	6000	514	64.04	5.68	9.99
	19.8	7000	380	64.86	5.74	9.65
	19.8	8000	278	64.67	6.30	9.50
Kraft 20	20.32	0	739	22.74	1.33	20.09
0.1% AQ	20.32	2000	658	64.18	5.08	12.88
	20.32	4000	536	69.98	5.44	11.02
	20.32	6000	399	70.53	6.17	10.86
	20.32	8000	292	74.58	6.29	10.06
Kraft 20	19.94	0	737	23.72	1.70	20.41
1.3 PS/0.1 AQ	19.94	2000	639	58.36	4.80	11.23
	19.94	4000	473	67.18	5.19	8.89
	19.94	6000	312	67.45	5.99	8.51
	19.94	7000	252	69.22	6.53	8.42
Kraft 20	20.84	0	749	23.98	1.64	19.35
1 PS/0.1 AQ	20.84	2000	658	62.53	4.67	11.64
	20.84	4000	505	66.38	5.52	9.70
	20.84	6000	342	69.61	5.63	9.09
	20.84	7000	300	66.01	5.79	9.04

Bleachability studies

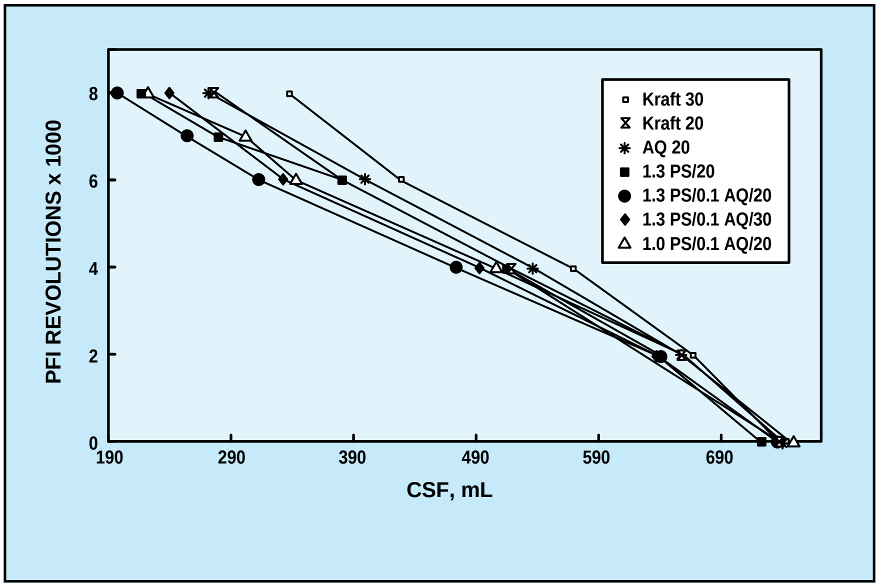
The bleachability of conventional kraft, AQ, PS, and PS/AQ pulps were evaluated using the bleaching sequence OD(EOP)D. The data are shown in **Table VII.**

The results obtained are shown in **Table VIII.** The same % NaOH was used in the oxygen stage for all the cases. As a result, the percent delignification was higher for the kappa no. 20 pulps compared to the kappa no. 30 pulps. The same kappa factor (0.22) was used in the D1 stage. The % ClO_2 in the D2 stage was interpolated to a constant brightness of 87%.

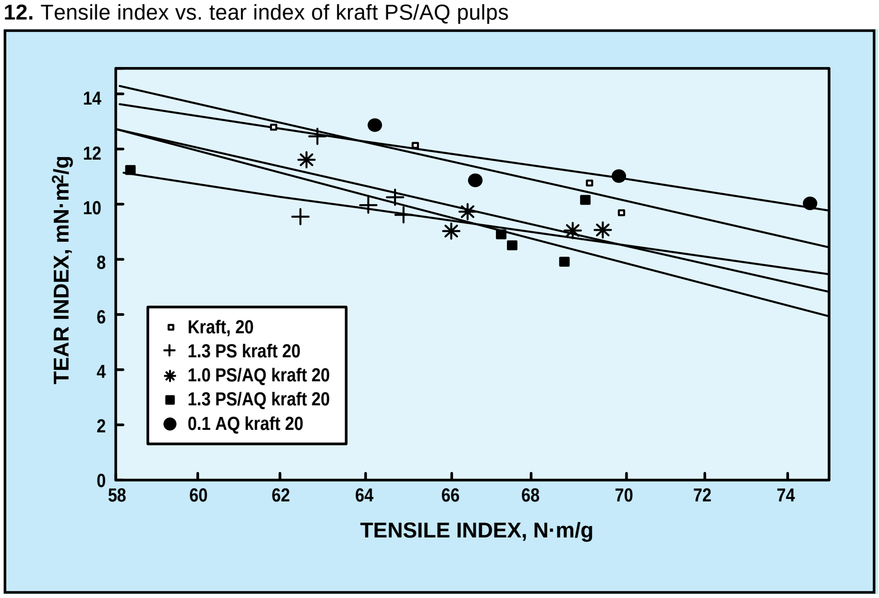
For kappa no. 30 pulps, the chlorine dioxide used to achieve a brightness of 87% was significantly higher for the AQ/PS pulp than the conventional kraft pulp. The P number after the (EOP) stage in the kraft PS/AQ pulp is higher (2.1) than the number for kraft pulp (1.8). However, the bleaching response is worse than expected for this difference. The results indicate that kappa no. 30 PS/AQ pulps have lower bleachability.

The bleachability of pulps with kappa numbers of approximately 20 are also shown in Table VIII. All kraft kappa no. 20 pulps required significantly lower chlorine dioxide in the D2 stage compared to the kappa no. 30 pulps to achieve a brightness of 87% ISO. The total chlorine dioxide consumption decreased from 2.14% on pulp for the kappa no. 30 kraft pulp to approximately 1.5% for the extended

11. Relationship between PFI revolutions and freeness



12. Tensile index vs. tear index of kraft PS/AQ pulps



delignified pulps. However, all the AQ and AQ/PS pulps required slightly higher chlorine dioxide charges in the D2 stage to achieve an 87% ISO brightness compared to the kraft pulp at kappa no. 20. Other researchers *(1, 3)* had found the bleachability of the AQ pulps to be comparable to that of kraft.

Strength properties of pulps

The viscosities of the bleached and the unbleached pulps are shown in Table VIII. At kappa no. 30, the viscosity of the kraft and the PS/AQ pulps was comparable for the unbleached and the bleached cases. The unbleached viscosities of the extended delignified pulps were lower, resulting in lower bleached viscosities. The kappa no. 20 AQ pulp had the best bleached viscosity.

The strength properties of the bleached pulps are shown in **Table IX.** The bleached pulp from kraft kappa no. 30 required the greatest number of PFI revolutions to reach a certain freeness (**Fig. 11**). The bleached AQ, PS, and AQ/PS pulps required less revolutions on the PFI. Higher retention of hemicelluloses in these pulps most likely contributed to this phenomenon.

Tear vs. tensile and burst vs. tensile strength are shown in **Figs. 12 and 13,** respectively. The kraft pulp at kappa no. 30 and the AQ pulp at kappa no. 20 had similar tear/tensile relationships. All the pulps produced using polysulfide (PS and PS/AQ) showed a 5–10% decrease in tear at the same tensile strength. Similar 5–10% lower tear strength has also been reported *(8–12).* Pekkala *(13)* had found that the tear strengths decreased only moderately for the PS/AQ pulps to kappa no. 20. He also found that below this value, the tear strength decreased more rapidly. The burst for all the pulps was comparable.

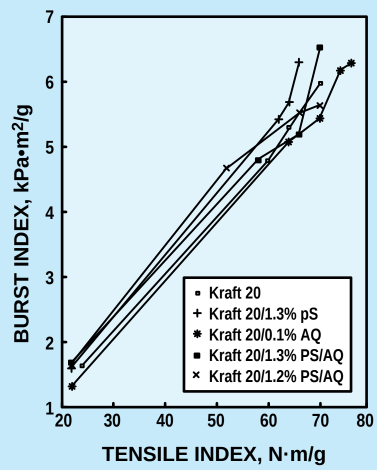
Zero-span tensile strengths for the bleached pulps are shown in **Table X.** At approximately kappa no. 30, the AQ/PS pulp had a higher zero-span tensile than the kraft pulp. At the lower kappa range (kappa no. 20), the PS/AQ pulps also have higher zero-span tensile than the kraft or kraft/AQ pulps. If the zero-span tensile strength is considered to be the intrinsic strength of the fiber, then the pulps with PS/AQ show a higher fiber strength. Paper strength properties showed lower tear strength for the polysulfide pulps. The lower tear strengths may be due to the higher hemicellulose content and differences in refining for the polysulfide pulps. With optimized refining conditions, it may be possible to correct for the lower strength, since the inherent fiber strengths of the polysulfide pulps are better.

Conclusions

This study shows that low-kappa-number pulps can be produced by adding AQ and PS individually or in combination. Other conclusions are as follows:

- The pulping studies show that with the use of AQ, the kappa number can be decreased by 15% at the same pulping conditions. If PS is used individually, no significant decrease in kappa number was measured, even when the % AA use was increased from 19 to 20%. If PS and AQ are used in combination, the decrease in kappa number was 15%, but the alkali use required an increase from 19 to 20%. If lower kappa numbers are desired for PS and PS/AQ, higher alkali and/or H factors will be necessary.
- A significant yield increase was measured by using AQ, PS, or AQ/PS. This increase can be used to decrease the kappa number without increasing the recovery boiler load. With 1.3% PS and 0.1% AQ, kappa numbers as low as 20 can be achieved without affecting the yield as compared to conventional kappa no. 30 kraft. Use of AQ or PS (1.3%) enabled us to pulp to kappa nos. 26 and 24, respectively.
- All kraft kappa no. 20 pulps required significantly lower chlorine dioxide as compared to kappa no. 30 to achieve an 87% ISO brightness. However, all the AQ and AQ/PS pulps required slightly higher chlorine dioxide charges in the D2 stage to achieve 87% ISO brightness as compared to the kraft pulp at kappa no. 24.
- The kraft pulp at kappa no. 30 and the AQ pulp at kappa no. 20 had similar tear vs. tensile strength relationships. All the pulps produced using polysulfide (PS and PS/AQ) showed a 5–10% decrease in tear at the same tensile strength. The burst for all the pulps was comparable. The zero-span tensile strength of the polysulfide pulps is higher than that of the kraft pulps.

13. Burst index vs. tensile index of kraft PS/AQ pulps



X. Zero-span breaking length of PS/AQ pulps

Bleached pulps	*Zero span, m*
Kraft 30	9,794
PS/AQ 30 1.3%/0.1%	13,547
Kraft 20	9,165
Kraft 20 1.3% PS	11,403
AQ 20	9,736
Kraft 20 PS/AQ 1.3%/0.1%	13,735
Kraft 20 PS/AQ 1%/0.1%	10,108

- It is possible to extend delignification to kappa nos. 20–22 using AQ and PS. If a mill needs to extend delignification at the highest yield, the best option is to use AQ/PS in combination. Yield increases of up to 4% can be achieved, enabling us to pulp to kappa no. 20 without increasing the recovery boiler load. The tear will be 5–10% lower than conventional kraft pulps (kappa no. 30). Higher chemical charges or H factors will be required.
- If the 5–10% tear strength decrease or the chemical charge is an issue, the best option is to use only AQ to extend delignification. The benefits of the yield increase will be lower, but the tear strength may be better, and the additional chemical or H factor requirement will be lower.

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