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Kraft Pulping of Sapwood-A Sawmill Waste

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ABSTRACT

This paper deals the effect of anthraquinone (AQ) on the contribution of sulphidity in kraft pulping of sapwood. The pulping conditions namely- active alkali concentration, pulpingtime, temperature and liquor ratio were varied in low (15%) and high (30%) sulphidity. 0.1% AQ was added in the low and high sulphidity pulping with varying active alkali concentration and cooking time. At optimum conditions, low sulphidity kraft process produced about 44% pulp yield with kappa number of about 23. But in high sulphidity kraft process kappa number was reduced to about 20 at the same yield. An addition of AQ reduced alkali requirement by 2% on oven dried raw material and cooking time by 1 hour to produce pulp yield of about 44% at kappa number 20. AQ is more effective in low sulphidity pulping than the high sulphidity pulping. The breaking length of kraft-AQ pulp was slightly higher than that of kraft pulp.

Keywords: *sapwood, kraft pulping, low sulphidity, high sulphidity, anthraquinone (AQ), delignification, pulp yield*

1. Introduction

The demand for pulp and paper in Bangladesh is increasing with literacy rate. All paper mills in Bangladesh depend on imported pulp. Therefore, it needs more pulp mills in Bangladesh. Presently only pulp mill KPM of Bangladesh uses bamboo and mixed hardwood as fibrous raw material. Unfortunately, existing conventional raw materials do not allow setting up more pulp mills in Bangladesh. Therefore, we have to find out alternative raw materials.

Saw mills of Bangladesh use heartwood for timber and reject sapwood. This sapwood is being now used as domestic fuel. So sapwood should be used in an alternative way, such as a pulping raw material.

The wood in young trees, and the outer wood of older trees, capable of conducting "sap" and contains living parenchyma which store carbohydrates, fats, and other food reserves, such wood tissue is commonly referred to as "sapwood" and is light in color (1). Sapwood is located between cambium and heartwood. The tran

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sition from sapwood to heartwood is accompanied by an increase in extractive content (2).

Many studies have been done on the difference between sapwood and heartwood pulping. Helena and Bruno (3) reported that the presence of heartwood in the raw material used for pulping decreased pulp yield and brightness mainly as a result of a higher content of extractives in relation to sapwood. The content of extractives differed largely between heartwood and sapwood, with respectively 19.7% and 5.8% on average. In a cross-section, the pulp yield of heartwood was always lower than those obtained from sapwood: on average 40.0% for heartwood and 49.7% for sapwood for similar delignification degree (kappa number). Pulp yield was inversely proportion tothe content of polar extractives (ethanol and water solubles). NSSC and sulfate pulping of *Populus* spp. showed that the heartwood and sapwood differ considerably in fiber length and in chemical properties. NSSC pulps from the sapwood have higher degree of whiteness, greater tear strength and slightly lower yields than the pulp from heartwood. However, there were no significant differences between heartwood and sapwood pulps as regard to tear strength, burst strength and residual lignin content. With sulfate pulps, the pulping condition significantly affected the quality of the pulp made from sapwood and heartwood; sulfate pulp from heartwood has slightly higher yield and higher ash content than those from sapwood, but, there was no significant difference as regards degree of whiteness or lignin content. Clone-dependent differences were found in the strength properties of sulfate pulps from sapwood and heartwood (4).

In the present investigation a study was done on the pulping of sapwood by kraft process with varying cooking variables. The effects of anthraquinone (AQ) on the contribution of sulphidity in kraft pulping have also been studied.

2. Experimental

2.1 Material

Sapwood was collected from the sawmill in Dhaka City. Sawmill in Bangladesh uses tropical hardwood for timber or other purposes. It was cut to about 1 cm in length, 1 cm in width and 0.5 cm in thickness.

2.2 Pulping

Pulping was carried out in a 20-l capacity electrically heated cylindrical batch digester and it was rotated by a motor. The normal charge was 1 kg of moisture free sapwood. The following parameters were maintained:

- The active alkali concentration was varied from 16 to 22% as Na_2O on oven dried (o.d.) sapwood for kraft process and kraft-AQ processes.
- Sulphidity was 15% and 30%
- The pulping temperature was varied from 160-180℃
- The pulpingtime was varied from 1 to 4 h at the maximum temperature.
- The liquor to material ratios was 4, 5 and 6.
- 0.1% AQ was in both low and high sulphidity kraft-AQ processes.

After digestion the pulp was washed till to free from residual chemical. The pulp yield was determined as percentage of oven-dry raw material. The kappa number of the pulps was determined according to Tappi Test Methods (T 236).

2.3 Evaluation of pulps

Sapwood pulp was beaten in a Valley beater and hand sheets of about 60 gm/m^2 were made in a Rapid Kothen Sheet Making Machine according to German Standard Methods number 106. The sheets were tested for tensile (T 404os 61), burst (T 403 om-97), tear strength (T 494 om-96) and double fold (T 423cm-98) according to Tappi Standard Test Methods.

3. Results and Discussion

Sapwood pulping in low and high sulphidity kraft process with and without AQ was performed with varying pulping variables namely- active alkali, pulping time, temperature and liquor ratio and shown in Tables 1-8.

3.1 Low sulphidity (15%) kraft pulping

Table 1 represents the pulp yield and pulp properties with the variation of active alkali. The pulping time was held constant for 3 h at 170℃ It is clearly seen from the Table 1 that there was a large acceleration of delignification rate when active alkali was increase from 16 to 18%, after that the increase of delignification rate was reduced with further increase of active alkali. Pulp yield was decreased with increasing active alkali. The physical properties of sapwood pulp were increased with increasing active alkali up to 20% then decreased. This is in good agreement with the studies of alkaline pulping of wood and nonwood(5, 6).

Table 2 shows the effect of pulping time on the pulp yield and pulp properties of low sulphidity kraft pulps from sapwood. It is clearly seen from Table 2 that pulp yield and kappa numbers were decreased rapidly with increasing pulping time up to 3 h. The increase of pulping time from 3 to 4 hour reduced the kappa number only 1.2 units. This was possibly due to the residual stage of pulping. The physical properties of kraft pulp at low sulphidity in different pulping time are also shown in Table 2. All physical properties were improved with increasing pulping time up to 3 h then decreased with increasing pulping time.

Table 1. Effect of active alkali concentration on the pulp yield and pulp properties in kraft pulping of sapwood

AA (% on wood)	Pulp yield (%)	Kappa number	Tear Index (mN · m^2/g)	Burst index (kPa · m^2/g)	Breaking length (km)	Double fold number
16	45.8	27.3	7.4	3.6	5.6	401
18	44.9	23.2	7.5	4.0	5.7	443
20	43.9	22.6	8.0	4.1	5.9	441
22	39.6	19.2	7.7	3.8	5.8	395

AA: Active alkali, Pulping time 3 h at 170 °C, liquor ratio 5,Sulphidity 15 %, Beating: 40 °SR

Table 2. Effect of pulping time on the pulp yield and pulp properties in kraft pulping of sapwood

Pulping time (h)	Pulp yield (%)	Kappa number	Tear Index (mN · m^2/g)	Burst index (kPa · m^2/g)	Breaking length (km)	Double fold number
1	49.6	30.2	7.7	3.3	5.2	297
2	47.4	24.3	7.9	3.8	5.7	391
3	43.9	22.6	8.0	4.1	5.9	441
4	40.4	21.4	7.3	3.7	5.4	414

AA 20%, temperature 170℃, liquor ratio 5, Sulphidity 15%, Beating: 40 °SR

Table 3. Effect of temperature on the pulp yield and pulp properties in kraft pulping of sapwood

Pulping temperature(℃)	Pulp yield (%)	Kappa number	Tear Index ($mN \cdot m^2/g$)	Burst index ($kPa \cdot m^2/g$)	Breaking length (km)	Double fold number
160	43.0	29.8	7.3	3.7	5.2	369
170	43.9	22.6	8.0	4.1	5.9	441
180	40.1	23.6	6.9	3.8	5.4	400

Pulping time 3 h, AA 20%, liquor ratio 5, Sulphidity 15%, Beating: 40 °SR

Table 4. Effect liquor ratio on the pulp yield and pulp properties in kraft pulping of sapwood

Liquor ratio	Pulp yield (%)	Kappa number	Tear Index ($mN \cdot m^2/g$)	Burst index ($kPa \cdot m^2/g$)	Breaking length (km)	Double fold number
4	46.2	24.3	7.8	3.9	5.8	425
5	43.9	22.6	8.0	4.1	5.9	441
6	47.8	27.2	7.7	4.2	5.4	435

Pulping time 3 h at 170℃, AA 20%, Sulphidity 15%, Beating: 40 °SR

The effect of temperature on pulp yield and pulp properties is shown in Table 3. Over a given period, kappa number decreased as temperature increased. The yield decreased with an increase in temperature because the reaction velocity constant increased for both delignification and carbohydrate degradation reaction. The physical properties were increased with the increase of temperature from 160 to 170℃ then decreased with further increase of temperature to 180℃.

To ensure the bulk penetration in all chips, it is important that sufficient liquor be charged to the digester to immerse the chips completely. To find out an optimum liquor ratio required in sapwood pulping it was varied and shown in Table 4. It is seen that 1:5 liquor ratio was the most suitable in kraft pulping. There were no significant effects on the physical properties of sapwood kraft pulp with the variation of liquor ratio.

3.2 High sulphidity (30%) kraft pulping

The effect of active alkali charge at higher sulphidity on the pulp yield and pulp properties are shown in Table 5. The experiments were carried out at 170℃ under a constant reaction time of 3 h. The yield decreased from 46.1% at 16% active alkali to 40.2% at 22% active alkali, while the corresponding drop in kappa number was from 21.6 to 17.1. The physical properties were increased with an increase of active alkali from 16% to 18% then again further increase of active alkali decreased

Table 5. Effect of active alkali on the pulp yield and pulp properties in high sulphidity kraft pulping of sapwood

AA (% on wood)	Pulp yield (%)	Kappa number	Tear Index ($mN \cdot m^2/g$)	Burst index ($kPa \cdot m^2/g$)	Breaking length (km)	Double fold number
16	46.1	21.6	8.0	3.6	5.8	455
18	43.9	20.9	7.9	4.4	6.0	496
20	43.4	19.8	7.8	4.2	6.1	461
22	40.2	17.1	7.5	3.9	5.9	432

AA: Active alkali, Pulping time 3 h at 170℃, liquor ratio 5, Sulphidity 30%, Beating: 40 °SR

Table 6. Effect of pulping time on the pulp yield and pulp properties in high sulphidity kraft pulping of sapwood

Pulping time (h)	Pulp yield (%)	Kappa number	Tear Index (mN · m^2/g)	Burst index (kPa · m^2/g)	Breaking length (km)	Double fold number
1	48.1	32.9	7.7	3.8	5.8	439
2	44.4	22.4	7.9	4.0	6.0	467
3	43.4	19.8	7.8	4.2	6.1	461
4	40.0	18.0	7.5	4.0	5.8	431

AA 20%, Temperature 170℃, liquor ratio 5, Beating: 40 °SR

strength properties.

A comparative drop in yield was observed for longer duration of pulping (Table 6). As expected the initial delignification rate was considerably faster than the later stage of pulping. Breaking length and burst index were increased with increasing pulping time from 1 to 3 h of pulping after this period of pulping these properties were decreased. But tear index and double fold number were increased up to 2 h then decreased.

3.3 Kraft-anthraquinone (AQ) pulping

Table 7 represents the effect of active alkali in the low and high sulphidity kraft-AQ pulping of sapwood. The delignification behaviors of sapwood in low and high sulphidity were almost similar in entire range of active alkali. Pulp yield was deceased to about 43 % at 18 % active alkali from 46 % at 16 % alkali in both sulphidities. All physical properties of sapwood kraft-AQ pulps were increased with increasing active alkali concentration from 16 to 18 % then decreased.

As is seen in Table 8 that pulp yield reduced from 47 to 38 % with kappa number 27 to 18 in increasing pulping time from 1 to 4 h in low sulphidity kraft-AQ process. High sulphidity kraft-AQ process showed pulp yield 47 to 40 % with almost similar kappa number in increasing pulping time from 1 to 4 h. Physical properties of both kraft-AQ pulps showed similar nature.

The effect of AQ in low and high sulphidity kraft pulping on the delignification of sapwood in respect to increasing active alkali is given

Table 7. Effect of active alkali on the pulp yield and pulp properties in low and high sulphidity kraft-AQ pulping of sapwood

AA (% on wood)		Pulp yield	Kappa number	Tear Index (mN · m^2/g)	Burst index (kPa · m^2/g)	Breaking length (km)	Double fold number
Low sulphidity	16	46.3	21.5	7.6	3.9	5.8	465
	18	43.6	20.8	7.9	4.2	6.1	452
	20	43.1	19.4	7.6	4.2	6.1	419
	22	40.2	16.9	7.3	4.0	5.9	412
High sulphidity	16	46.1	20.3	7.7	4.0	6.1	387
	18	43.8	20.3	7.8	4.1	6.2	393
	20	43.1	19.4	7.6	4.1	6.1	391
	22	40.2	17.1	7.1	3.9	5.8	364

Pulping time 2 h at 170℃, liquor ratio 5, Beating: 40 °SR

Table 8. Effect of pulping time on the pulp yield and pulp properties in low and high sulphidity kraft-AQ pulping of sapwood

Pulping time (h)		Pulp yield (%)	Kappa number	Tear Index (mN · m²/g)	Burst index (kPa · m²/g)	Breaking length (km)	Double fold number
Low sulphidity	1	46.9	26.7	7.7	4.0	5.9	369
	2	43.6	20.8	7.9	4.2	6.1	452
	3	41.4	18.1	7.7	4.3	6.0	434
	4	38.3	18.0	7.3	4.0	5.9	409
High sulphidity	1	47.4	27.4	7.7	4.1	5.8	335
	2	43.8	20.3	7.8	4.1	6.2	393
	3	42.1	18.4	7.6	4.2	6.3	357
	4	40.0	18.0	7.4	3.8	6.0	307

AA 18%, Temperature 170℃ liquor ratio 5, Beating: 40 °SR

in Fig. 1. A desired kappa number could be attained in the kraft 15 (low sulphidity) cook with 18 % active alkali. An addition of 0.1 % AQ in the liquor reduced the active alkali requirement by 16 % to reached the kappa number about <25. Kraft 30 (high sulphidity), kraft 30-AQ and kraft 15-AQ showed almost similar behavior.

Fig. 2 shows the effect of AQ in low and high sulphidity kraft delignification of sapwood in respect to cooking time. It is seen from Fig. 2 that the addition of AQ reduced the cooking time to reach a particular level of delignification. The desired kappa number <25 could be attained in low sulphidity kraft with cooking time of 3 h and in high sulphidity kraft below 3 h. The kappa number <25 and was reached in kraft 15-AQ cook in 2 h. It is thus observed that on the addition of AQ in the low sulphidity white liquor reduced the pulpingtime by 33%. An addition of AQ in the high sulphidity white liquor, same delignification was observed as in the low sulphidity. Therefore, AQ is more favorable in low sulphidity kraft pulping.

Compared with normal kraft pulping, kraft-AQ showed marked lower kappa number at similar pulp yield (Fig. 3). At pulp yield of

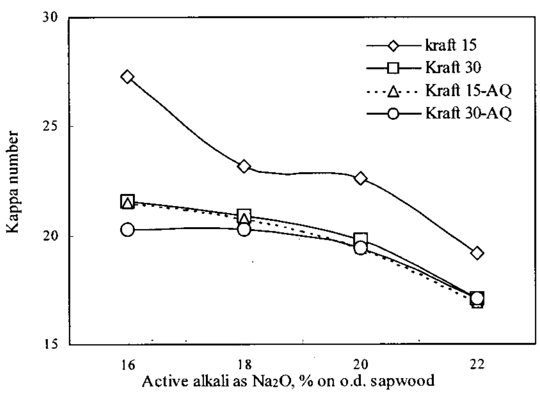

Fig. 1. Effect of active alkali on the delignification of sapwood in kraft and kraft-AQ pulping.

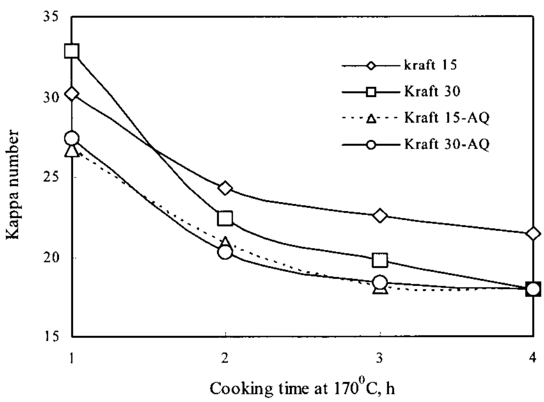

Fig. 2. Effect of pulping time on the delignification of sapwood in kraft and kraft-AQ pulping.

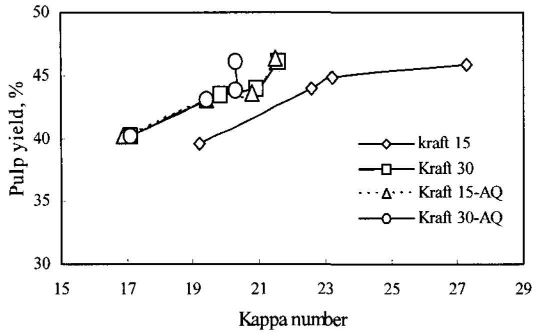

Fig. 3. Yield-Kappa relationship of kraft and kraft-AQ pulps from sapwood.

about 44%, high sulphidity kraft, kraft-AQ pulps showed almost similar kappa number that was about 3 points lower than the low sulphidity kraft. Tasman (7) observed an increase of 2 % pulp yield for Jack pine and a decrease of 0.3 % for Black spruce for a change in sulphidity from 20 to 35. Therefore, it appears that the magnitude of pulp yield change with sulphidity in kraft pulping is species-dependent. In the alkaline-AQ process, a nucleophilic addition of AHQ^{-2} to a lignin quinone methide to give an adduct, followed by an elimination reaction that regenerated AQ and lead to -aryl ether cleavage (8, 9). The predominant productive delignification event appeared to be cleavage of the abundant -aryl ether linkage (10).

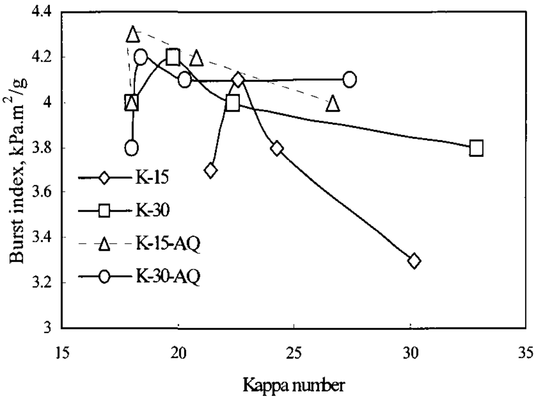

Fig. 5. The relationship between Kappa number and burst index of kraft and kraft-AQ pulps.

The influence of AQ on the breaking length of sapwood pulp at 40 oSR is presented in Fig. 4. The figure shows that an addition of AQ in low sulphidity kraft liquor produced pulp of about 4% higher breaking length at kappa number 25. Breaking length of kraft 30 and kraft 30-AQ coincided at kappa number 25. Therefore, it seems that AQ is more effective for low sulphidity kraft process.

The effect of AQ on the burst index of kraft pulp at 40 °SR is shown in Fig. 5. Kraft-AQ was superior as compared to normal kraft pulp.

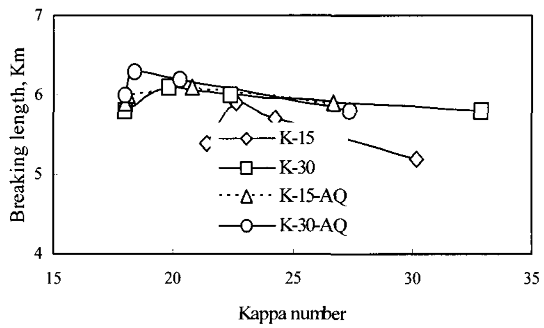

Fig. 4. The relationship between Kappa number and breaking length of kraft and kraft-AQ pulps.

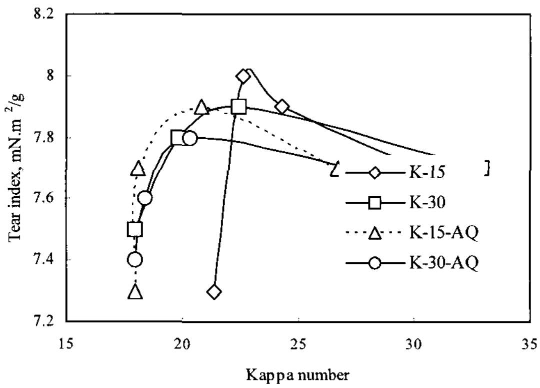

Fig. 6. The relationship between Kappa number and tear index of kraft and kraft-AQ pulps.

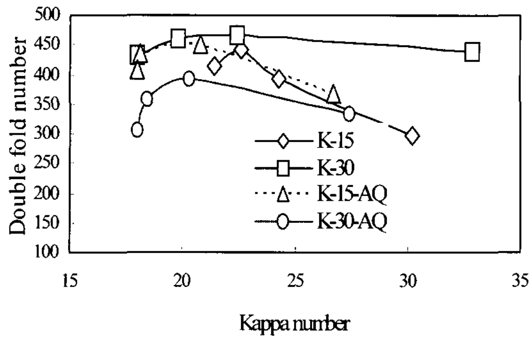

Fig. 7. The relationship between Kappa number and double fold number of kraft and kraft-AQ pulps.

The Fig. 5 shows that normal kraft-15 exhibited highest burst index value at kappa number 22 whereas kraft 15-AQ at kappa number 18. This value was about 14% higher than the normal kraft-15. Kraft-30-AQ gave about 5% higher burst index than the normal kraft-30 at kappa number 22.

The tear index of kraft-15-AQ pulp was almost similar to the normal kraft-30 pulp at kappa number about 20 as shownin Fig. 6. Kraft 30-AQ pulp showed lower tear index than the normal kraft pulp. Previously the loss in tear index in kraft-AQ pulping was observed with black spruce (11).

Fig. 7 shows the relationship between kappa number and double fold number at 40 oSR.

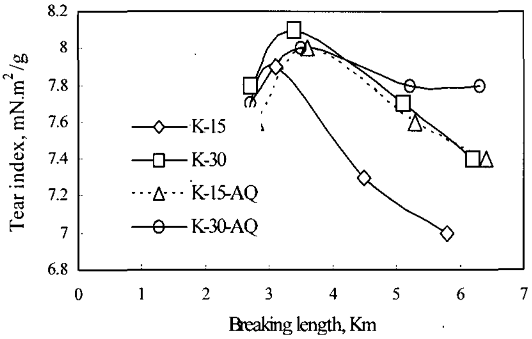

Fig. 8. Breaking length and tear index relationship of kraft and kraft-AQ pulps.

Kraft 15 produced highest double fold number at kappa number about 23 whereas kraft 15-AQ and kraft 30 at about kappa number 20. Kraft 15-AQ and kraft 30 showed almost similar value in the kappa number range 16-20. Unfortunately, kraft 30-AQ gave inferior results.

It is more common practice to look upon tensile-tear relationship. They are considered to be the most important strength properties and at the same time they are inversely related in the majority of the cases. Such a comparison for the pulp at almost similar degree of pulping(kappa number about 22) is drawn in Figure 8. The Figure shows that the tear strength of kraft-AQ and kraft 30 pulps at any breaking length was higher than the kraft 15 pulp. At higher breaking length, tear index of kraft 30, kraft-AQ pulp was much higher than the kraft 15. In the initial stage of beating, no significant differencewas observed between normal kraft and kraft-AQ pulp in respect to breaking length tear index relationship.

4. Conclusions

The following conclusions may be drawn from this investigation:

- Pulp yield and kappa number of sapwood in kraft process were decreased with increasing active alkali, pulping time or temperature.
- High sulphidity kraft process showed high pulp yield and lower kappa number than that of low sulphidity kraft process.
- High sulphidity kraft process produced pulp better strength properties as compared to low sulphidity kraft pulp.
- An addition of AQ in the kraft liquor decreased pulping time or active alkali requirement to produce of desired kappa

number with higher pulp yield.

- Low and high sulphidity kraft-AQ pulps gave almost similar pulp yield and kappa number. The strength properties were better in low sulphidity kraft-AQ pulp. Therefore, AQ is more effective in low sulphidity kraft process.

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