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L72

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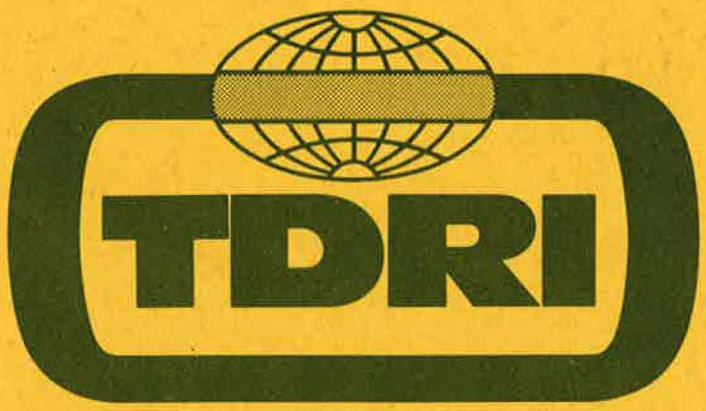

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Pulping characteristics of *Pinus oocarpa* from Uganda

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SUMMARY

Pulping characteristics of *Pinus oocarpa* from Uganda

The results of the examination of a sample of *Pinus oocarpa*, approximately 10 years old, grown in plantations in Uganda are reported and compared with those obtained from a sample grown in its natural habitat, Belize.

The sample from Uganda had a wood density of 382 kg m^{-3} which was much lower than that of the sample from Belize, 530 kg m^{-3}. The Ugandan sample also had a lower resin content and the fibres were shorter, narrower, and thinner-walled.

Using the sulphate pulping process, under different conditions the Ugandan sample yielded between 41.8% and 48.4% of pulp with a kappa number from 23.7 to 53.1.

Samples of *Pinus oocarpa* from their natural habitats are reported to yield pulps with properties similar to those of Southern pines from the USA, with high tearing strength, and moderate bursting and tensile strengths. The Ugandan samples yielded pulps with similar bursting and tensile strengths, but low tearing strength.

The effects are reported of bleaching the pulp by a four-stage sequence of successive applications of chlorine, sodium hydroxide, sodium hypochlorite and chlorine dioxide.

Differences between the Ugandan and Belize samples are principally attributed to the lower age of the former.

RÉSUMÉ

Caractéristiques de la production de pâte de *Pinus oocarpa* l'Ouganda

Les résultats de l'examen d'un échantillon de *Pinus oocarpa* d'environ 10 ans ayant poussé dans des plantations d'Ouganda sont présentés et comparés à ceux obtenus avec un échantillon ayant poussé dans son habitat naturel, Belize.

L'échantillon provenant de l'Ouganda avait une densité du bois de 382 kg par mètre cube, soit bien inférieure à celle de l'échantillon provenant de Belize, 530 kg par mètre cube. L'échantillon provenant de l'Ouganda avait également une plus faible teneur en résine et les fibres étaient plus courtes, plus étroites et à enveloppe plus fine.

En utilisant le procédé ân sulfate, le rendement en pâte de l'échantillon de l'Ouganda a varié dans différéntes conditions entre 41,8% et 48,4%, avec un indice kappa de 23,7 à 53,1.

On rapport que les échantillons de *Pinus oocarpa* provenant de leur habitat naturel fournissent des pâtes avec des propriétés semblables à celles des pâtes obtenues avec les pins du sud des Etats-Unis, avec une résistance au déchirement élévee et des résistances à l'éclatement et à la rupture par traction modérées. Les échantillons de l'Ouganda ont donné des pâtes avec des résistances à l'éclatement et á la rupture par traction comparables, mais une faible résistance au déchirement.

Les effets du blanchiment de la pâte par un procédé en quatre phases avec des applications successives de chlore, d'hydroxyde de sodium, d'hypochlorite de sodium et de bioxyde de chlore sont décrits.

Les différences entre les échantillons de l'Ouganda et de Belize sont attribuées principalement au plus jeune âge des premiers.

RESUMEN

Características de pulpación del *Pinus oocarpa* de Uganda

Se detallan los resultados del análisis de una muestra de *Pinus oocarpa*, de aproximademente 10 años de edad, cultivado en plantaciones de Uganda, y se comparan con los obtenidos de una muestra cultivada en su medio natural Belize.

La muestra procedente de Uganda registró una densidad de madera equivalente a 382 kg m^{-3}, la cual fue más baja que la muestra de Belize de 530 kg m^{-3}. La muestra de Uganda también registró un contenido de resina más bajo, y las fibras eran más cortas, estrechas y de paredes más delgadas.

Usando el proceso de pulpación por sulfato, bajo diferentes condiciones, la muestra de Uganda produjo entre 41,8% y 48,4% de pulpa con un número kappa entre 23,7 y 53,1.

Las muestras de *Pinus oocarpa* procedentes de sus medios natureles producen pulpas con propiedades similares a las de los pinos meridionales de los Estados Unidos, con una más alta resistencia al rasgado, y resistencias moderadas al reventón y a la tracción. Las muestras de Uganda produjeron pulpas con resistencias similares a la tracción y al reventón, pero resistencias inferiores al rasgado.

Los efectos son explicados del blanqueo de la pulpa mediante una secuencia de cuatro etapas de aplicaciones sucesivas de cloro, hidróxido de sodio, hipoclorito de sodio y dióxido de cloro.

Las diferencias entre las muestras de Uganda y Belize son atribuidas principalmente a la menor edad del primero.

Pulping characteristics of *Pinus oocarpa* from Uganda

INTRODUCTION

During the period of 1960–70 the Forestry Department in Uganda established experimental plantations of a number of fast-growing species. As part of a programme to determine the utilisation potential of these species, the pulping characteristics of a sample of *Pinus oocarpa* have been determined and are reported here.

Pinus oocarpa is indigenous to the mountainous uplands of Central America and Mexico. It has been introduced as an exotic plantation species, with favourable results, in many areas. It has been estimated that the total area planted globally with *P. oocarpa* up to 1977 was 23 400 ha, and it is included in the commercial planting programme in several countries (Greaves, 1982).

Information on the pulping characteristics of *P. oocarpa* is limited to three reports of the examination of samples from its natural habitat and two of samples grown in exotic plantations. Samples from Honduras, pulped by the sulphate process, required pulping conditions similar to those for US Southern pines and yielded a pulp from which wrapping paper with high tearing strength and moderate bursting and tensile strengths was made (Le Cacheux *et al.*, 1959). Other samples from Honduras were pulped by chemical and mechanical processes in the USA. The results of the chemical pulping trials were similar to those reported earlier and an acceptable quality newsprint was made from *P. oocarpa* groundwood pulp, mixed with 20–25% of bleached sulphate pulp from Southern pines (Schafer and Chidester, 1961). A sample from Belize, pulped by the sulphate process, was also reported to yield pulps similar to those from Southern pines, with good tearing strength but less satisfactory bursting and tensile strengths; the yields were rather low, 38–44% (Palmer and Gibbs, 1976).

The two samples from exotic plantations came from the Congo and Brazil. That from the Congo was 7 years old and was readily pulped by the kraft process but the bursting and tensile strengths, whilst superior to those of pulps from *P. caribaea* grown in the Congo, were inferior to pulps from *P. patula* from Swaziland (Tissot, 1968). Sulphate pulping of samples 6, 12 and 13 years old from a plantation in the São Paulo State, Brazil showed that with increasing age the pulp yield and the bursting, tensile and tearing strengths all increased (Foelkel *et al.*, 1975).

The investigation reported here contributes to information on the pulping characteristics of *P. oocarpa* grown in exotic plantations.

SAMPLES

The sample of *P. oocarpa* was grown in a plantation established at the Katugo Forest Research Station using seed from Mountain Pine Ridge, Belize. When the

sample trees were felled the plantation was approximately 10 years old. The Katugo Forest Research Station is situated 1° 08′ N, 32° 27′ E at an elevation of 1 082 m*.

Five trees were selected by random numbers from the plantation and eight logs were cut from each tree at 5, 15, 25, 35, 45, 55, 65 and 75% of the total height. Subsequently, each log was cut into discs 20 mm thick. One disc from each log was used for the determination of wood density; the rest were chipped, and the chips mixed to form a sample representative of the five trees which was used for chemical analysis, fibre measurements and pulping.

EXPERIMENTAL RESULTS AND DISCUSSION

Wood density measurements and chemical analyses were carried out in accordance with the standard methods published by TAPPI. Pulps were evaluated using sheets formed on a British Standard sheet machine, and tested in an atmosphere controlled at 23° ± 2°C and 50% ± 2% relative humidity. The tests were according to the appropriate British Standards, which are generally the same as ISO and TAPPI Standards. Full details of the experimental methods used can be found in the appendix to *Report of the Tropical Products Institute,* L63 (Palmer *et al.,* 1982)

Wood density was determined using a disc from each sampling point, thus giving a measure of variation within and between trees. All other determinations were made on a sample prepared by chipping an equal number of discs from each sampling point and thoroughly mixing the chips so that they were representative of the whole sample. A portion of this mixed chip sample was ground for chemical analysis.

Wood density

The apparent density of wood was measured as (oven-dry mass)/(green volume) for a disc from each log. A mean density for each tree and for the sample was evaluated as (total mass of discs)/(total volume of discs). The average value and the range of values within each tree are given in Table 1. The average density for the sample, 382 kg m^{-3}, was in the range often found for pines grown in the tropics. The range of density between and within trees was small.

The density of this wood is much lower than the value (530 kg m^{-3}) measured at TDRI (Palmer and Gibbs, 1976) for a sample from Belize. The lower age of the sample from Uganda (10 years, as compared with between 20 and 46 years) would have contributed to this difference. The variation of density within and between trees was much less for the sample from Uganda, and is attributed to their uniform age.

Chemical analysis

The proportions of chemical constituents that affect the pulping characteristics of woods were determined on a ground sample of the wood. The results are reported in Table 2.

The resin content, as measured by the proportion of the wood extracted by alcohol-benzene (1.1%) was low. The lignin (28.9%), holo-cellulose (65.2%) and alpha-cellulose (41.9%) contents were all similar to those usually found in pine species. Consequently, no difficulty was expected, or experienced, in pulping by the sulphate process.

The only significant difference between their values and those for the sample from Belize (Palmer and Gibbs, 1976) related to the resin content (3.82% for the latter), and was again most likely due to age.

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*GOODWIN-BAILEY, C. I. (1984) Personal communication

Fibre dimensions

The fibre (tracheid) length, width and wall thickness were determined by measuring the magnified image of fibres from a well-cooked sulphate pulp. The length was also estimated by classification in a McNett classifier. The results are reported in Table 3.

The fibres from this sample were a little, probably not significantly, shorter, narrower and thinner-walled than the fibres from the sample from Belize (Palmer and Gibbs, 1976): differences again attributed to age.

The fibres were supple and expected to give a well-bonded sheet.

Chemical pulping and unbleached pulp evaluation

The sample was pulped by the sulphate process using four different amounts of chemical charge; the other digestion conditions were constant. The most severe conditions were intended to produce a pulp with a kappa number about 25, suitable for bleaching. The other conditions were intended to produce higher yields of stronger pulps. Each digestion was duplicated and the results reported are the average for the two digestions. The strength characteristics of the pulps were determined by forming sheets on a British Standard sheet machine, and testing after conditioning in an atmosphere of 23° ± 2°C and 50% ± 2% relative humidity.

Details of the pulping conditions, pulp yields, kappa number, and pulp strength characteristics at fixed drainability values, are recorded in Table 4.

Four digestions were made with the active alkali (expressed as $Na_2 0$ on oven-dry wood) in the cooking liquor successively increased from 15% to 20%. This increase in severity of cooking had a marked effect on pulp yield, which reduced from 48.4% to 41.8%, and on kappa number (an indirect measurement of the lignin content of the pulp) which reduced from 53.1 to 23.7. There was very little difference in the strength of the pulps obtained using the different conditions.

Bleaching conditions and bleached pulp evaluation

The unbleached pulp obtained by the most severe digestion conditions, with a kappa number of 23.7, was used for bleaching. A simple four-stage sequence, of successive applications of chlorine, sodium hydroxide, sodium hypochlorite and chlorine dioxide, was used. Only one bleaching trial was made, without determining the optimum conditions; consequently the results were only an indication of the potential bleachability. Details of the bleaching conditions and of the evaluation of the bleached pulp are reported in Table 5.

The total amount of chlorine applied to the dry unbleached pulp was 10%; the resultant bleached pulp had an ISO brightness of 79 and the loss of pulp was 5%. The strength characteristics of the bleached pulp were about 5% lower than those of the unbleached pulp. The brightness of this pulp was lower than would be expected of a fully-bleached chemical pulp, but it is likely that a more complex procedure with more stages and the optimum conditions determined would yield brighter pulps. The strength characteristics were above those required for printing and writing papers.

Detailed data on the evaluation of unbleached and bleached pulps are given in Table 6.

Comparison with commercial pulpwoods

Pulps prepared in the laboratory cannot be compared directly with industrial pulps because of differences in operating conditions. Therefore, in order to assess the value of the samples being examined, it is necessary to compare the properties of their pulps with the properties of pulps prepared in the same laboratories from wood used in the pulp industry. In this case comparison has been made with Southern pines of the USA and *Pinus patula* from Swaziland which were pulped in this laboratory.

Details of pulping conditions and the strength characteristics of the pulps obtained from these commercial pulpwoods are summarised in Table 7.

For pulps prepared under the same conditions, the yields and kappa numbers are all comparable; this suggests that the present sample of *P. oocarpa* could be usefully pulped under the same conditions as those used industrially for Southern pines in the USA and for *P. patula* in Swaziland. The pulps from *P. oocarpa* had higher bursting and tensile strengths but lower tearing strength than the pulps from Southern pines. Strength properties of pulps from *P. oocarpa* were closer to those of the pulps from *P. patula* but again the tearing strength of pulps from *P. oocarpa* was lower. Consequently, it is unlikely that *P. oocarpa* similar to this sample could be used for the production of pulp where tearing strength is a critical parameter, but it could be used for general purposes. It will be noted that this finding does not confirm earlier reports (Le Cacheux *et al.*, 1959; Schafer and Chidester, 1961) that pulp from *P. oocarpa* had a good tearing strength. The difference is, almost certainly, because this sample of plantation grown wood was younger than the wood from natural forests used in earlier tests. Older material from plantations may yield pulps with higher tearing strength and thus be more acceptable for use in the production of packaging papers.

REFERENCES

FOELKEL, C. E. B., BARRICHELO, L. E. G., AMARAL, A. C. B. do and VALE, C. F. do (1975) Variation in the wood characteristics and the properties of pulp from *Pinus oocarpa*. *IPEF*, **10**, 81–87.

GREAVES, A. (1982) *Pinus oocarpa*. *Forestry Abstracts*, **43**, 503–532.

LE CACHEUX, P. M., TUDDO, A. de, HUGUET, L. *et al.* (1959) Project for the manufacture of pulp and paper in Central America. *Food and Agriculture Organization of the United Nations Report,* FAO/CAIS/59/1, 378 pp.

PALMER, E. R. and GIBBS, J. A. (1976) Pulping characteristics of *Pinus oocarpa* grown on Mountain Pine Ridge, Belize. *Report of the Tropical Products Institute,* L44, iv + 21 pp.

PALMER, E. R., JOHNSON, J. S., GANGULI, S., GIBBS, J. A. and DUTTA, A. P. (1982) Pulping trials on *Pinus patula* and *Pinus radiata* grown in plantations in Kenya. *Report of the Tropical Products Institute,* L 63, iv + 56 pp.

SCHAFER, E. R. and CHIDESTER, G. H. (1961) Pulping and papermaking experiments on certain pines of Mexico and Central America. *United States Department of Agriculture, Forest Products Laboratroy, Madison, Report No.* 2217, 34 pp.

TISSOT, M. (1968) Caractéristiques papetières de quelques pins introduit en Afrique et á Madagascar. *Bois et Forêts des Tropiques,* **118**, 41–55.

Table 1

Wood density

Tree number	Density, kg m^{-3}	
	Average	Range
1	351	328–362
3	362	338–379
5	434	392–465
7	365	326–397
9	381	353–404

Note: Mean density of sample, 382 kg m^{-3}

Table 2

Chemical analysis

	Percentage by weight
Cold water solubles	1.5
Hot water solubles	1.5
Alcohol-benzene solubles	1.1
Total solubles *	3.2
1% NaOH solubles	10.8
Lignin	28.9
Holo-cellulose	65.2
Alpha-cellulose	41.9

Notes: All values expressed as percentage oven-dry solubles or component on oven-dry unextracted wood

* Total amount dissolved by successive treatments with alcohol-benzene, alcohol and hot water in preparation of an extractive-free sample of wood for lignin, holo-cellulose and alpha-cellulose determinations

Table 3

Fibre dimensions by projection and classification of sulphate pulps

Fibre dimensions by projection

Length, mm		Width, μm	Wall thickness, μm
All fibres	Whole fibres		
1.98 (0.06)	2.97 (0.06)	40.9 (0.7)	4.2 (0.1)*

Fibre weight fractions by classification, %

Passed aperture, μm	–	1 680	1 190	841	595	420	210	74†
Retained on aperture, μm	1 680	1 190	841	595	420	210	74	–
	43.8	17.9	15.4	7.6	7.2	4.7	1.5	1.9

Fibre length calculated from classification = 3.0 mm

Notes: * Figures in brackets are the standard error of the mean for each determination

† By difference

Table 4

Sulphate digestion conditions, unbleached pulp yield and evaluation

Cook number	MK 408		MK 409		MK 406		MK 407	
Digestion conditions								
Active alkali as Na_2O on oven-dry wood, %	15		16.25		17.5		20	
Sulphidity, %	25		25		25		25	
Liquor to oven-dry wood ratio	5:1		5:1		5:1		5:1	
Maximum temperature, °C	170		170		170		170	
Time to reach maximum temperature, hours	1		1		1		1	
Time at maximum temperature, hours	4		4		4		4	
Active alkali consumed on over-dry wood, %	12.5		13.1		14.1		15.2	
Pulp yield								
Yield of oven-dry digested pulp on oven-dry wood, %	48.4		46.1		45.2		41.8	
Yield of oven-dry screened pulp on oven-dry wood, %	45.7		45.3		45.0		41.8	
Yield of oven-dry screenings on oven-dry digested pulp, %	5.6		1.7		0.4		0.0	
Pulp evaluation								
Kappa number of screened pulp	53.1		43.2		33.7		23.7	
Drainability, CSF	500	300	500	300	500	300	500	300
Beating time, P. F. I., minutes	5.6	8.1	4.9	7.5	4.7	7.1	4.6	7.1
Bulk, cm^3g^{-1}	1.44	1.39	1.44	1.38	1.43	1.37	1.41	1.34
Burst index, kPa m^2g^{-1}	6.6	7.1	6.5	7.1	6.5	6.7	5.7	6.4
Tensile index, N m g^{-1}	100	103	100	110	102	110	90	100
Stretch, %	3.2	3.3	3.3	3.2	3.2	3.1	3.3	3.4
Tear index, mN m^2 g^{-1}	11.2	10.5	11.9	10.5	11.4	10.1	11.8	10.7
Double folds, Kohler-Molin, number	1 250	1 450	1 300	1 450	1 200	1 200	1 250	1 400

Table 5

Bleaching conditions, bleached pulp yield and evaluation

Cook number	MK 407	
Kappa number	23.7	
Bleaching conditions		
1 Chlorination for 1 hour at 20°C, pulp consistency 3%		
Chlorine applied as Cl_2 on oven-dry unbleached pulp, %	6.4	
Chlorine consumed as Cl_2 on oven-dry unbleached pulp, %	5.5	
2 Alkali extraction for 1 hour at 60°C, pulp consistency 6%		
NaOH on oven-dry unbleached pulp, %	3	
3 Hypochlorite for 2 hours at 35°C, pulp consistency 6%		
Sodium hypochlorite as available Cl_2 on oven-dry unbleached pulp, %	1	
Available Cl_2 consumed on oven-dry unbleached pulp, %	0.96	
4 Chlorine dioxide for 3 hours at 70°C, pulp consistency 6%		
ClO_2 applied as Cl_2 equivalent on oven-dry unbleached pulp, %	2.63	
ClO_2 consumed as Cl_2 equivalent on oven-dry unbleached pulp, %	2.34	
Total chlorine applied as Cl_2 on oven-dry unbleached pulp, %	10.03	
Total chlorine consumed as Cl_2 on oven-dry unbleached pulp, %	8.80	
Yield		
Oven-dry bleached pulp on oven-dry unbleached pulp, %	94.8	
Oven-dry bleached pulp on oven-dry wood, %	39.6	
Pulp evaluation		
ISO brightness, unbeaten pulp, %	79.3	
Specific scattering co-efficient, unbeaten sheets, $cm^2\ g^{-1}$	367	
Drainability, CSF	500	300
Beating time, P. F. I., minutes	4.4	6.7
Bulk, $cm^3\ g^{-1}$	1.39	1.34
Burst index, kPa $m^2\ g^{-1}$	5.65	6.08
Tensile index, N m g^{-1}	90	89
Stretch, %	3.2	3.2
Tear index, mN $m^2\ g^{-1}$	11.3	10.0
Double folds, Kohler-Molin, number	1 120	1 260
Printing opacity, %	64	59
Specific scattering co-efficient, $cm^2\ g^{-1}$	170	150

Table 6

Sulphate pulp evaluation

Beaten in P.F.I. mill

Cook number	Kappa number	Beating time	Drain-ability	Drainage time	Air resistance $100cm^3/6.45cm^2$	Bulk	Burst index	Tensile index	Stretch	Tear index	Double folds, Kohler-Molin 7.85N	ISO Brightness	Printing opacity	Specific scattering coefficient
		minutes	CSF	seconds	seconds	$cm^3\ g^{-1}$	kPa m^2g^{-1}	N m g^{-1}	%	mN m^2g^{-1}	number	%	%	$cm^2\ g^{-1}$
Unbleached														
MK 408	53.1	0	745	4.5	0.5	2.270	2.6	46.9	1.9	16.80	707	16.9		
		1	728	4.5	1.2	1.620	4.8	76.9	5.0	15.50	1 216	12.2		
		3	660	4.6	3.3	1.513	6.3	92.6	3.1	12.65	1 303	10.6		
		5	548	4.6	11.3	1.458	6.4	97.1	3.2	11.25	1 216	10.0		
		7	395	4.9	76.3	1.413	7.0	100.5	3.2	11.05	1 333	9.2		
		9	257	5.7	425.8	1.383	7.2	103.1	3.2	10.39	1 513	9.5		
MK 409	43.2	0	732	4.4	0.7	2.078	3.0	57.1	2.0	16.00	870	18.1		
		1	720	4.4	1.9	1.560	4.7	79.9	2.7	15.60	1 122	13.5		
		3	628	4.5	6.6	1.446	6.2	91.5	3.0	12.05	1 412	11.3		
		5	491	4.7	19.7	1.443	6.5	99.6	3.2	11.90	1 288	10.6		
		7	333	5.0	185.7	1.388	7.0	108.7	3.2	10.55	1 513	9.9		
		9	243	6.0	815.0	1.364	7.2	110.5	3.1	10.45	1 412	9.9		
MK 406	33.7	0	730	4.3	0.7	1.994	3.1	53.7	2.2	18.15	741	19.4		
		1	705	4.3	2.2	1.578	4.8	77.3	2.7	15.00	1 148	15.2		
		3	623	4.6	6.1	1.464	5.6	90.4	2.9	12.50	1 202	12.6		
		5	475	4.7	30.8	1.419	6.6	102.7	2.9	11.30	1 122	12.3		
		7	308	5.3	273.3	1.375	6.7	109.1	3.1	10.20	1 230	11.5		
MK 407	23.7	0	733	4.3	0.9	2.017	2.7	48.7	2.2	17.90	630	22.5		
		1	715	4.6	2.0	1.554	3.9	68.2	2.8	15.50	954	17.5		
		3	633	4.7	5.9	1.451	5.3	83.0	3.2	13.15	1 258	14.6		
		5	428	5.2	58.2	1.393	5.9	92.8	3.1	11.00	1 174	13.7		
		7	305	5.7	326.3	1.349	6.3	100.6	3.4	10.65	1 412	12.8		
Bleached														
MK 407		0	735	4.3	0.5	2.151	1.7	34.2	2.4	15.10	64	78.4	78	367
		1	725	–	1.8	1.585	3.5	60.7	2.7	16.90	741	73.0	71	251
		3	625	4.5	7.4	1.438	5.1	82.3	3.1	12.70	1 023	70.6	64	190
		5	468	4.9	39.3	1.380	5.8	93.8	3.1	11.00	1 174	68.9	61	165
		7	280	6.0	252.8	1.335	6.1	86.0	3.2	9.98	1 148	67.4	59	150

Table 7

Commercial coniferous pulpwoods: sulphate digestion conditions, unbleached pulp yield and evaluation

Species	Southern pines Southern USA				*Pinus patula* Swaziland			
Cook number	MK 95		MK 94		MK 309		MK 310	
Digestion conditions								
Active alkali as Na_2O on oven-dry wood, %	17.5		20		17.5		20	
Sulphidity, %	25		25		25		25	
Liquor to oven-dry wood ratio	5:1		5:1		5:1		5:1	
Maximum temperature, °C	170		170		170		170	
Time to reach maximum temperature, hours	1		1		1		1	
Time at maximum temperature, hours	4		4		4		4	
Active alkali consumed on oven-dry wood, %	12.7		13.5		13.6		14.2	
Pulp yield								
Yield of oven-dry digested pulp on oven-dry wood, %	45.5		43.7		44.1		41.7	
Yield of oven-dry screened pulp on oven-dry wood, %	43.7		42.9		43.7		41.6	
Yield of oven-dry screenings on oven-dry screened pulp, %	4.0		1.9		0.8		0.3	
Pulp evaluation								
Kappa number	37.1		29.5		35.0		27.8	
Drainability, CSF	500	300	500	300	500	300	500	300
Beating time, P.F.I., minutes	4.2	6.8	3.7	6.4	3.5	5.6	3.2	5.4
Bulk, $cm^3\ g^{-1}$	1.49	1.47	1.54	1.47	1.54	1.47	1.54	1.47
Burst index, $kPa\ m^2\ g^{-1}$	5.6	5.9	5.6	5.9	6.8	7.2	6.3	6.9
Tensile index, $N\ m\ g^{-1}$	85	91	82	87	103	108	97	103
Tear index, $mN\ m^2\ g^{-1}$	15.4	14.3	14.9	14.0	13.3	12.6	12.6	11.7
Double folds, Kohler-Molin, number	935	1 025	870	1 025	1 070	1 175	1 000	1 150