Tropical Products Institute

L57

Pulping characteristics of *Pinus caribaea* grown in Sri Lanka

Tropical Products Institute

L57

Pulping characteristics of *Pinus caribaea* grown in Sri Lanka

E. R. Palmer and S. Ganguli

April 1982

Tropical Products Institute 56/62 Gray's Inn Road London WC1X 8LU
Overseas Development Administration

This report was produced by the Tropical Products Institute, a British Government organisation which co-operates with developing countries in helping them to derive greater benefit from their plant and animal resources. It specialises in post-harvest problems and will be pleased to answer requests for information and advice addressed to the Director.

Price £2.40 including packing and postage.

No charge is made for single copies of this publication sent to governmental and educational establishments, research institutions and non-profit making organisations working in countries eligible for British Aid. Free copies cannot normally be addressed to individuals by name but only under their official titles.

Tropical Products Institute
ISBN: 0 85954 150–9
ISSN: 0144–2325

Contents

TABLES IN APPENDIX

Summaries

SUMMARY

Pulping characteristics of *Pinus caribaea* grown in Sri Lanka

Three samples of *Pinus caribaea* grown in Sri Lanka were examined. One sample, aged nine years, was grown on an evergreen forest site; the other two, aged 20 and 22 years, were grown on a Montane forest site.

The average density of the wood of the three samples was: 548 kg per cubic metre (9-year old), 476 kg per cubic metre (20-year old) and 377 kg per cubic metre (22-year old). The youngest sample had the highest cellulose and the lowest lignin contents.

Sulphate pulps were obtained from all samples without difficulty with an unbleached screened yield of 45—47% at kappa numbers around 40. The youngest sample yielded pulps with the highest tearing strengths and the lowest tensile and bursting strengths. There was insufficient information to reach a firm conclusion of the reasons for these unexpected findings, but it is suggested that the difference in growing conditions caused differences in wood quality so great that the expected progression of density, chemical composition and pulp properties with age were disguised.

All pulps with a kappa number less than 30 were bleached using a chlorination, alkali-extraction, sodium hypochlorite, chlorine dioxide sequence. Bleached pulps with ISO-brightness of 82.5—84 were obtained in yields of 40—43%. The most satisfactory results were obtained from the bleaching of pulps with a kappa number between 25 and 30.

If the *P. caribaea* samples were pulped as a mixture, they would most likely yield a pulp with properties similar to those of pulps from Douglas Fir and Southern Pines, and most useful for sack and packaging grades of paper. They could be useful also, especially those from the Kottawa site, if mixed with straw pulps to increase strength characteristics.

RÉSUMÉ

Caractéristiques de la production de pâte de *Pinus caribaea* cultivé en Sri Lanka

Trois échantillons de *Pinus caribaea* cultivé en Sri Lanka ont été examinés. Un échantillon, âgé de neuf ans, avait poussé dans une station forestiére de plantes à feuilles persistantes; les deux autres, âgés de 20 et 22 ans, avaient poussé dans une station forestière de montagne.

La densité moyenne du bois des trois échantillons était la suivante: 548 kg par mètre cube (9 ans), 476 kg par mètre cube (20 ans) et 377 kg par mètre cube (22 ans). L'échantillon le plus jeune présentait la teneur la plus élevée en cellulose et la teneur la plus faible en lignine.

Les pâtes au sulfate ont été obtenues à partir de tous les échantillons sans difficulté avec un rendement en pâte écrue après classage de 45—47% à des indices kappa d'environ 40. L'échantillon le plus jeune a donné des pâtes avec les résistances au déchirement les plus élevées et les résistances à la rupture par traction et à l'éclatement les plus faibles. Les informations recueillies étaient insuffisantes pour parvenir à une conclusion solide quant aux raisons de ces résultats inattendus, mais on laisse entendre que la différence des conditions de croissance a provoqué des différences de qualité du bois à tel point importantes que l'évolution prévue de la densité, de la composition chimique et des propriétés de la pâte avec l'âge a été masquée.

Toutes les pâtes avec un indice kappa inférieur à 30 ont été blanchies en utilisant un traitement dans l'ordre suivant: chloruration, extraction aux alcalis, hypochlorite de sodium, bioxyde de chlore. Des pâtes blanchies avec une blancheur 150 de 82,5 — 84 ont été obtenues avec des rendements de 40—43%. Les résultats les plus satisfaisants ont été obtenus par blanchiment des pâtes avec un indice kappa entre 25 et 30.

Si les échantillons de *P. caribaea* avaient été réduits en pâte sous forme de mélange, ils auraient très probablement donné une pâte avec des propriétés semblables à celles des pâtes obtenues à partir du sapin de Douglas et du pin du Sud et convenant particulièrement aux qualités de papier à sacs et d'emballage. Elles pourraient être utiles aussi, en particulier celles provenant de la station de Kottawa, en mélange avec des pâtes de paille, pour augmenter les caractéristiques de résistance.

RESUMEN

Características de pulpación ofrecidas por el *Pinus caribaea* cultivado en Sri Lanka

Fueron estudiadas tres muestras de *Pinus caribaea* cultivadas en Sri Lanka. Una de ellas, de nueve años de edad, fue cultivada en un emplazamiento forestal de hojas perennes, mientras que las otras dos — de 20 y 22 años de edad — fueron cultivadas en un emplazamiento forestal montañoso.

La densidad media de la madera de las tres muestras fue de 548 kg por metro cúbico (la de 9 años de edad), 476 kg por metro cúbico (la de 20 años) y 377 kg por metro cúbico (la de 22 años). La muestra más jóven ofreció el nivel más elevado de celulosa y el contenido menor de lignina.

Fueron obtenidas sin dificultad pulpas de sulfato de las tres muestras, con una producción clasificada no blanqueada de 45—47% a unos 40 en números kappa. La muestra más jóven produjo pulpas que ofrecieron las más altas resistencias al rasgado y las más bajas resistencias a la tracción y a la rotura. No hubo una información suficiente para llegar a una conclusión firme que explicara los motivos de estos inesperados descubrimientos, pero se ha sugerido que la diferencia en las condiciones del cultivo causaron diferencias tan grandes en la calidad de la madera que la progresión esperada de la densidad, de la composición química y de las propiedades de la pulpa con la edad fueron disfrazadas.

Todas las pulpas con un número kappa inferior a 30 fueron blanqueadas usando una secuencia de clorinación, extracción, alcalina, hipoclorito sódico, dióxido de cloro. Pulpas blanqueadas con una luminosidad ISO de 82, 5—84 en producciones del 40—43% fueron obtenidas. Los resultados más satisfactorios fueron obtenidos a partir del blanqueado de pulpas con un número kappa entre 25 y 30.

Si las muestras de *P. caribaea* fueran pulpadas como una mezcla lo más probable es que produjeran una pulpa con propiedades parecidas a las de las pulpas procedentes del abeto Douglas y del pino Meridional, las cuales son sumamente útiles para fabricar grados de papel apropiados para sacos y embalajes. Podrían también ser útiles, especialmente las procedentes del emplazamiento de Kottawa, si se mezclan con pulpas de paja con el fin de incrementar sus características de resistencia.

Pulping characteristics of *Pinus caribaea* grown in Sri Lanka

INTRODUCTION

Sri Lanka has a small pulp and paper industry. Estimates for 1980 were an annual paper and board capacity of 25,000 tonnes, and production of 20,000 tonnes. This quantity of paper was made using 8,000 tonnes of straw pulp produced in Sri Lanka, 8,000 tonnes of imported wood pulp and some recycled paper. In addition, 17,000 tonnes of paper and board were imported (PPI, 1981).

In order to increase the range of papers made and to reduce imports of both pulp and paper, proposals have been made for an integrated pulp and paper mill, pulping soft and hardwoods and kenaf (FAO, 1981).

The purpose of this investigation was to evaluate the softwood, *Pinus caribaea,* which is being grown in plantations in Sri Lanka.

SAMPLES

The samples of *P. caribaea* used in this investigation came from three trial plots:

1. Kottawa – trees 9 years old.
2. Aththalapitiya – trees 20 years old.
3. Erabedde – trees 22 years old.

The sample grown at Kottawa is *P. caribaea* var. *hondurensis,* the seed having been obtained from a Dutch seed merchant, but the precise provenance of the seed is not known. The samples grown at Aththalapitiya and Erabedde are believed to be var. *hondurensis* but no records are available concerning the source of the seeds.

The following information about the growing conditions and the rate of growth was provided by the Forest Department, Sri Lanka.

1. Sample from Kottawa – age 9 years
   Growing conditions – wet evergreen forest
   Rate of growth – height increment 80 cm per annum
   Average girth – 45 cm
   Average height – 7 metres
2. Sample from Aththalapitiya – age 20 years
   Growing conditions – Montane forest
   Rate of growth – height increment 80 cm per annum
   Average girth – 60 cm
   Average height – 18.5 metres

3. Sample from Erabedde — age 22 years
   Growing conditions — Montane forest
   Rate of growth — height increment 90 cm per annum
   Average girth — 70 cm
   Average height — 20 metres

The rate of growth at Erabedde was a little greater than on the other sites, but the average difference between sites was less than the difference between trees on any one site.

For the pulping trials, ten trees were selected at random from each area. Five logs were cut from each tree at 10, 30, 50, 70 and 90% of the total height of the tree. The cut ends of the logs were treated with sodium pentachlorophenate to reduce the effect of sap stain fungus.

The dimensions of the trees in the sample indicate that the trees selected in the nine year old plantation at Kottawa were amongst the more vigorous trees, but the average height and girth of the trees in the samples from Aththalapitiya and Erabedde were near to the average for the site.

The logs were cut into discs about 20 mm thick, split along the grain to produce strips about 5–6 mm thick, using a mechanical guillotine, and the strips were further broken to lengths of about 20 mm. Chips made from an equal number of discs from each log, representing the entire site, were thoroughly mixed and used for chemical analysis and pulping trials. Fibre dimensions were determined using fibres from unbeaten sheets of well cooked pulps generated during the pulping trials. One whole disc of uniform thickness from each log was used for density determination.

EXPERIMENTAL RESULTS AND DISCUSSION

Full details of the experimental techniques and the method of calculating results are given in the Appendix.

Bark content

The amount of bark on each log was determined as the proportion of the whole log (including bark) both by volume and by weight. The average results are given in Table 1 and the detailed data for all logs are given in Table 2.

Table 1

Bark content and density of samples

District	Age years	Bark content, %				Density‡, kg m^{-3}	
		By volume*		By weight†			
		Average	Range between trees	Average	Range between trees	Average	Range between trees
Kottawa	9	28.3	18.8–36.1	14.6	10.1–24.3	548	385–655
Aththalapitiya	20	17.1	9.4–25.3	9.1	6.0–11.9	476	418–533
Erabedde	22	19.1	15.0–24.9	12.9	10.4–15.7	377	319–462

Notes:

* Expressed as: $\frac{\text{volume of bark}}{\text{volume of bark + volume of wood}}$% (as received)

† Expressed as: $\frac{\text{weight of oven dry bark}}{\text{weight of oven dry bark + weight of oven dry wood}}$ %

‡ Oven dry weight/green volume

Table 2

Bark content of individual trees and logs at various heights

District	Age years	Tree identity	Bark content by weight, %						Bark content by volume, %					
			Height, %					Tree weighted mean	Height, %					Tree weighted mean
			10	30	50	70	90		10	30	50	70	90	
Kottawa	9	1	19	15	15	14	21	16	37	28	26	29	30	31
		2	10	9	10	11	12	10	20	20	21	20	23	20
		3	15	11	12	11	16	13	25	14	18	14	12	19
		4	13	10	10	10	18	11	32	30	22	23	26	28
		5	16	16	14	14	18	15	33	29	25	21	26	29
		6	13	11	9	11	10	11	29	22	23	21	21	25
		7	12	12	13	13	20	12	27	26	24	25	29	26
		8	16	14	13	15	25	15	36	26	24	25	30	29
		9	19	17	17	15	20	18	39	30	29	35	19	34
		10	23	23	24	28	38	24	49	40	40	37	38	36
Mean district value								15						28
Aththalapitiya	20	1	12	12	12	12	15	12	28	26	24	21	15	25
		2	11	11	10	12	14	11	21	15	17	15	14	18
		3	6	6	4	6	14	6	13	8	7	7	13	9
		4	13	8	8	9	15	11	23	21	17	13	18	20
		5	8	7	6	8	13	7	20	15	8	11	10	15
		6	7	8	8	9	12	8	19	17	16	17	12	17
		7	7	7	10	10	14	8	20	13	14	13	18	16
		8	12	7	7	8	15	10	23	14	11	11	14	17
		9	9	8	10	9	12	9	17	14	18	9	12	15
		10	10	8	7	10	16	9	27	16	8	12	18	18
Mean district value								9						17
Erabedde	22	1	13	11	12	10	10	12	17	15	15	12	12	15
		2	17	12	12	9	12	14	22	18	16	14	9	18
		3	12	10	9	11	15	11	20	18	15	14	14	17
		4	17	13	10	12	12	14	32	20	15	16	16	24
		5	18	15	12	10	16	16	21	13	15	10	12	16
		6	11	10	10	10	14	10	18	14	11	14	16	16
		7	17	13	13	14	15	15	27	26	21	22	25	25
		8	13	16	14	16	18	14	26	24	23	21	25	24
		9	11	10	10	11	16	11	24	19	14	16	19	20
		10	16	13	12	11	12	14	21	15	14	13	13	16
Mean district value								13						19

The average bark content by site was:

Site	By weight %	By volume %
Kottawa	15	28
Aththalapitiya	9	17
Erabedde	13	19

These bark contents were higher than are usually found in temperate pine species used for pulp but similar to those found in other tropical pines. The proportion of bark is important because the bark is not used for pulping and consequently a proportion of the material being taken to the pulp mill may be unused. Bark can be used for fuel however, and in planning any mill allowance should be made for this.

Density

The density of the wood was determined as oven dry weight/green (soaked) volume. The weighted mean densities and the range for each site are given in Table 1 and the details for the individual logs are given in Table 3. Average values for each site were: Kottawa, 548 kg per cubic metre; Aththalapitiya, 476 kg per cubic metre; and Erabedde, 377 kg per cubic metre.

The observed decrease of density with age was unexpected. However, it is known that growing conditions can have a considerable effect on wood density, and that the density of trees grown at high elevations has been found to be less than that of trees grown at sea level. No detailed information was available concerning growing conditions, but the fact that Aththalapitiya and Erabedde are described as Montane forest may partly explain the difference.

Table 3

Tree dimensions and density of individual trees and logs at various heights

District	Age years	Tree identity	Tree height, m		Over bark girth at % height, cm					Density, kgm^{-3}					
			At 8 cm diam.	Total	10	30	50	70	90	Height, % 10	30	50	70	90	Tree weighted mean
Kottawa	9	1	7.30	8.50	56.0	47.0	36.0	31.5	15.5	605	607	620	592	548	605
		2	8.10	10.00	61.0	52.0	44.0	33.0	16.5	643	674	657	605	557	649
		3	6.50	8.10	49.0	41.5	37.0	27.5	15.5	414	390	382	336	272	385
		4	6.60	9.20	46.0	40.0	33.5	24.5	14.0	642	655	559	519	422	604
		5	9.10	11.15	52.0	44.5	38.0	27.0	21.0	600	553	518	499	459	550
		6	7.30	10.25	48.0	39.0	32.0	22.0	18.0	693	691	693	672	597	685
		7	7.15	9.40	44.5	39.0	34.5	26.5	16.0	690	648	591	580	483	637
		8	8.90	10.10	55.0	49.0	42.5	37.0	21.5	517	461	447	389	311	454
		9	5.45	9.15	59.0	46.5	32.0	15.5	8.0	463	456	485	447	316	463
		10	6.10	7.60	63.0	52.5	44.5	38.5	16.5	556	468	433	399	343	476
Mean district value			7.25	9.35	53.4	45.1	37.4	28.3	16.3						548
Aththalapitiya	20	1	17.10	18.70	66.5	58.0	50.0	36.5	19.0	599	506	546	405	362	533
		2	16.20	18.00	68.0	63.0	55.0	45.0	20.5	490	449	426	381	371	445
		3	16.40	18.20	65.0	63.0	56.0	41.5	22.5	608	499	435	386	341	494
		4	19.25	20.50	91.0	77.5	62.0	45.5	27.0	567	453	416	374	325	473
		5	16.80	19.00	63.0	57.0	46.0	36.5	19.5	575	506	463	401	350	501
		6	19.00	20.00	66.0	63.0	55.5	45.0	25.0	557	498	491	408	365	495
		7	17.80	20.30	76.0	65.0	54.0	37.0	21.5	504	451	432	388	355	454
		8	15.20	17.30	62.0	53.0	44.0	34.0	20.0	482	413	380	351	324	418
		9	12.80	15.50	50.0	43.0	38.0	27.0	16.0	519	463	371	340	354	443
		10	10.50	14.10	55.0	47.0	37.5	25.0	13.0	577	533	451	394	324	513
Mean district value			16.11	18.16	66.3	59.0	49.8	37.3	20.4						476
Erabedde	22	1	21.00	22.50	74.5	64.0	51.5	41.0	32.5	347	317	338	329	342	335
		2	19.30	20.00	92.5	81.0	67.0	50.0	31.0	372	352	340	392	319	359
		3	19.80	20.10	65.5	59.0	51.5	42.0	28.5	463	412	384	373	340	411
		4	16.90	19.00	69.0	56.0	44.0	35.0	24.0	343	320	316	313	302	326
		5	13.15	16.40	68.5	58.0	46.0	30.5	13.3	343	303	290	336	297	319
		6	20.00	21.70	67.0	53.0	43.0	34.5	24.5	493	443	427	406	354	451
		7	17.55	20.40	62.0	54.0	44.0	35.0	17.5	394	373	360	336	332	372
		8	17.80	18.50	83.5	75.5	62.5	50.0	30.0	416	390	367	342	386	387
		9	17.30	20.20	78.5	65.5	53.5	36.0	20.5	533	461	393	379	347	462
		10	18.60	20.90	68.5	59.0	48.5	38.5	22.5	370	343	328	326	335	347
Mean district value			18.14	19.97	73.0	62.5	51.2	42.3	24.4						377

The mean density of trees from Kottawa is higher than that of *P. caribaea* var. *hondurensis* of similar age grown in Sabah (Palmer and Gibbs, 1971), Fiji (Palmer and Gibbs, 1972) and Belize (Palmer and Gibbs, 1976).

The density of temperate pines commonly used in the pulping industry is 310 to 560 kg per cubic metre (Rydholm, 1965), and values for all the samples were within that range.

Fibre dimensions

The fibre dimensions were determined by direct measurement of the magnified image of the fibres from unbeaten sheets of well-cooked sulphate pulps using a projection microscope. The lengths were determined, also by classification of a well-cooked sulphate pulp, using the McNett classifier. The mean value for the length, width and wall thickness, and the standard error of the mean are given in Table 4.

The average length of fibres from the sample from Kottawa (9 years old) was 2.31 ± 0.07 mm; from Aththalapitiya (20 years old) 2.85 ± 0.07 mm; and from Erabedde (22 years old) 2.87 ± 0.09 mm. It was expected that the older samples would have longer fibres and that there would be no significant difference between the two older samples. Classification showed no significant difference in fibre lengths of any sample. This was due to the fact that a very large proportion of the fibres was retained on the coarsest screen and this prevented an accurate estimate of length.

Fibres from pines grown in the tropics are usually more coarse than those from pines grown in temperate zones. In this investigation the fibre width (30–38 μm) was closer to that of temperate grown pines than to that of other tropical grown pines examined at TPI. The wall thickness (5.1–5.6 μm) was greater than is usually found in temperate pines and typical of the values found for tropical pines, and it is usual to find wall thickness increasing with age.

Chemical analysis

The results of proximate chemical analyses are given in Table 5.

In these three samples there was a decrease in cellulose content and an increase in lignin content with age. Again, this was an unexpected finding: for tropical pines the cellulose content usually increases, and the lignin content usually decreases, with age. It is possible that differences in growing conditions – the younger sample grown in wet evergreen forest, and the older two in Montane forest – were sufficient to reverse the expected trends.

Results of the chemical analyses suggested no likely problems with sulphate pulping.

Pulping and pulp evaluation

Several sulphate digestions were made on each sample. The severity of digestion conditions was varied in order to obtain a number of pulps with qualities ranging from the strong packaging grades to bleachable grades for writing papers.

As was expected, no difficulties were experienced in sulphate pulping. In general the strongest pulps were those with a kappa number ca. 40 and a screened yield of 45–47%, produced using active alkali concentrations of 15–17.5%. Less severe digestion conditions yielded pulp with a kappa number ca. 50 and a total yield of around 50%. These pulps had a high level of screen rejects with consequently lower screened yields, and were usually a little weaker and more difficult to beat than more severely cooked pulps. More severe pulping conditions yield 43–45% of screened pulp with a kappa number ca. 25 and suitable for bleaching. The bleachable pulps were easier to beat but had strength characteristics lower than the pulps with kappa number ca. 40.

The two older samples were easier to digest than the nine-year old sample from Kottawa. The former had the higher lignin content but this was compensated for by lower density, allowing easier liquor-penetration.

Table 4

Fibre dimensions by projection and classification of sulphate pulp

District	Age years	Fibre dimensions by projection: Length, mm: All fibres	Length, mm: Whole fibres	Width µm	Wall thickness µm	Fibre weight fractions by classification, %: Passed aperture, µm / Retained on aperture, µm: — / 1,680	1,680 / 1,190	1,190 / 841	841 / 595	595 / 420	420 / 210	210 / 74	74† / —	Calculated‡ fibre length by classification, mm
Kottawa	9	1.68 (0.07)*	2.31 (0.07)	30.5 (0.67)	5.1 (0.14)	51.3	13.0	11.6	6.9	7.8	5.4	1.5	2.5	3.02
Aththalapitiya	20	2.17 (0.08)	2.85 (0.07)	30.1 (0.90)	5.6 (0.16)	54.6	13.7	11.8	4.4	6.5	4.8	2.0	2.2	3.09
Erabedde	22	1.99 (0.09)	2.87 (0.09)	38.0 (0.98)	5.5 (0.17)	61.4	10.5	8.8	5.1	6.1	4.2	1.4	2.5	3.16

Notes:
* Figures in brackets are the standard errors of the mean for each determination
† By difference
‡ See appendix

Table 5

Chemical analysis of each sample

District	Age years	Alcohol-benzene extractives %	Alcohol extractives %	Total extractives* %	Holocellulose %	Alpha-cellulose %	Lignin %	1% NaOH solubility %	Hot water solubility %	Cold water solubility %
Kottawa	9	0.8	0.2	2.0	67.2	46.1	26.6	11.0	1.3	1.7
Aththalapitiya	20	1.1	0.3	1.4	63.6	43.9	27.4	10.5	1.7	2.3
Erabedde	22	1.1	0.2	2.4	63.4	42.7	28.3	11.1	1.5	1.6

Notes:
All expressed as oven dry extractives or component on oven dry unextracted wood
* Successive extractions in alcohol-benzene, alcohol and hot water to prepare an extractive free sample for subsequent examination

Comparison of the strength properties of the strongest pulp from each of the three samples reveals that the youngest sample from Kottawa had the highest tearing strength and the lowest tensile and bursting strengths. Usually tearing strength increases with age, and tensile and bursting strengths decrease with age, but the present finding is consistent with the other unexpected findings concerning density and chemical composition; again the indication is that growing conditions had a greater effect than age on the quality of wood.

Table 6

Sulphate digestion conditions, pulp yield and evaluation Kottawa

	Drainability CSF	Cook number		
		MK571	MK573	MK575
Digestion conditions				
Active alkali as Na_2O on oven dry wood, %		15.0	17.5	20.0
Sulphidity, %		25	25	25
Liquor to oven dry wood ratio		5:1	5:1	5:1
Maximum temperature, °C		170	170	170
Time to reach maximum temperature, h		1	1	1
Time at maximum temperature, h		4	4	4
Chemical consumption				
Active alkali consumed as Na_2O on oven dry wood, %		12.8	14.1	14.2
Yield of pulp				
Yield of oven dry digested pulp on oven dry wood, %		50.8	46.2	44.0
Yield of oven dry screened pulp on oven dry wood, %		44.8	45.2	43.7
Yield of screenings on oven dry digested pulp, %		11.8	2.2	0.7
Pulp evaluation				
Kappa number		53.4	35.5	26.5
Beating, rev.	500	8,010	6,860	6,010
	300	11,730	10,010	8,870
Apparent density, gcm^{-3}	500	0.58	0.59	0.60
	300	0.59	0.62	0.63
Tensile index, Nmg^{-1}	500	74.8	76.5	73.7
	300	81.7	82.8	81.0
Tear index, mNm^2g^{-1}	500	17.0	19.5	16.8
	300	16.1	18.0	15.6
Burst index, $kPam^2g^{-1}$	500	4.85	5.08	4.66
	300	5.30	5.46	5.14
Folding endurance	500	2.95	2.90	2.80
	300	2.98	2.94	2.90
Air resistance, s	500	3.4	3.9	4.3
	300	26	29	52

Table 7

Sulphate digestion conditions, pulp yield and evaluation Aththalapitiya

	Drainability CSF	Cook number MK596	MK597	MK587	MK589	MK591
Digestion conditions						
Active alkali as Na_2O on oven dry wood, %		13.75	15	15	17.5	20
Sulphidity, %		25	25	25	25	25
Liquor to oven dry wood ratio		5:1	5:1	5:1	5:1	5:1
Maximum temperature, °C		170	170	170	170	170
Time to reach maximum temperature, h		1	1	1	1	1
Time at maximum temperature, h		4	3	4	4	4
Chemical consumption						
Active alkali consumed as Na_2O on oven dry wood, %		12.2	12.2	12.6	13.5	13.8
Yield of pulp						
Yield of oven dry digested pulp on oven dry wood, %		49.8	51.0	48.5	45.1	42.8
Yield of oven dry screened pulp on oven dry wood, %		46.9	47.8	47.3	45.0	42.8
Yield of screenings on oven dry digested pulp, %		5.9	6.4	2.4	0.2	0.1
Pulp evaluation						
Kappa number		55.0	47.1	41.8	27.0	21.1
Beating, rev.	500	8,870	8,870	8,150	7,150	6,860
	300	12,870	12,580	12,580	11,150	10,010
Apparent density, gcm^{-3}	500	0.57	0.58	0.57	0.60	0.60
	300	0.59	0.61	0.60	0.62	0.62
Tensile index, Nmg^{-1}	500	86.0	85.3	88.0	89.3	85.8
	300	89.8	91.9	93.5	94.7	93.5
Tear index, mNm^2g^{-1}	500	15.5	16.2	16.6	16.3	16.2
	300	14.6	15.1	15.5	14.9	15.0
Burst index, $kPam^2g^{-1}$	500	5.72	5.77	5.76	5.76	5.47
	300	6.10	6.13	6.20	6.06	5.98
Folding endurance	500	2.94	2.98	2.96	2.92	2.84
	300	2.98	3.02	3.02	2.95	2.91
Air resistance, s	500	3.4	3.7	3.0	4.7	4.9
	300	34	30	35	55	45

The oldest, Erabedde, sample was the most difficult to beat, and except for the more severely digested pulps, the most prolonged beating conditions used did not reduce the Canadian standard freeness (CSF) to 300. This was probably due to the thick fibre walls of this sample. Details of pulping conditions, pulp yield and strength values at 500 and 300 Canadian standard freeness are given in Tables 6 (Kottawa), 7 (Aththalapitiya) and 8 (Erabedde). The full pulp evaluation results are given in Tables 9 (Kottawa), 10 (Aththalapitiya) and 11 (Erabedde).

Bleaching and bleached pulp evaluation

All of the pulps with a kappa number less than 30 were bleached by a chlorination, alkali-extraction, sodium hypochlorite and chlorine dioxide (CEHD) sequence. One pulp from Kottawa site, and two each from Aththalapitiya and Erabedde sites, were thus bleached.

The amount of chlorine used in the chlorination stage depended on the kappa number of the pulp, but quantities of materials used in subsequent stages were maintained constant. The total amount of chlorine added varied from 9.1% for pulp with a kappa number of 21, to 11.5% for pulp with a kappa number of 28.2. In each case approximately 90% of the chlorine added was consumed. The loss of pulp on bleaching was approximately 5%, giving bleached pulp yields (based on original oven dry wood) of 40–43%.

Table 8

Sulphate digestion conditions, pulp yield and evaluation
Erabedde

	Drainability CSF	Cook number				
		MK593	MK594	MK579	MK581	MK583
Digestion conditions						
Active alkali as Na_2O on oven dry wood, %		13.75	15.0	15.0	17.5	20.0
Sulphidity, %		25	25	25	25	25
Liquor to oven dry wood ratio		5:1	5:1	5:1	5:1	5:1
Maximum temperature, °C		170	170	170	170	170
Time to reach maximum temperature, h		1	1	1	1	1
Time at maximum temperature, h		4	3	4	4	4
Chemical consumption						
Active alkali consumed as Na_2O on oven dry wood, %		11.8	12.1	12.6	12.8	13.6
Yield of pulp						
Yield of oven dry digested pulp on oven dry wood, %		50.1	48.2	47.3	43.6	42.2
Yield of oven dry screened pulp on oven dry wood, %		46.1	46.2	46.1	43.5	42.1
Yield of screenings on oven dry digested pulp, %		8.0	4.1	2.4	0.2	0.2
Pulp evaluation						
Kappa number		56.2	47.2	44.7	28.2	22.6
Beating, rev.	500	11,010	10,870	10,150	8,720	7,720
	300	–	–	–	12,580	11,300
Apparent density, gcm^{-3}	500	0.64	0.65	0.65	0.66	0.67
	300	–	–	–	0.68	0.69
Tensile index, Nmg^{-1}	500	101	98.4	100	100	92.9
	300	–	–	–	106	101
Tear index, mNm^2g^{-1}	500	13.8	13.7	13.8	13.5	13.2
	300	–	–	–	12.2	11.9
Burst index, $kPam^2g^{-1}$	500	7.24	7.01	6.90	6.53	5.80
	300	–	–	–	6.94	6.25
Folding endurance	500	3.20	3.20	3.20	3.13	3.12
	300	–	–	–	3.16	3.15
Air resistance, s	500	12	14	12	14	13
	300	–	–	–	120	160

The pulps had an ISO-brightness of 82.5–84. The bleached pulps had, on average, 90% of the strength of the unbleached pulps. However this value depended on the pulp and the property being considered; in general the unbleached pulps with kappa numbers over 25 were stronger than the unbleached pulps with kappa numbers under 25 and the former pulps retained a higher proportion of their strength. Although a higher amount of bleaching chemical is required, there are advantages in bleaching pulps with a kappa number of between 25 and 30.

Details of bleaching conditions and a summary of the bleached pulp strength at 500 and 300 CSF are given in Table 12. Full evaluations of bleached pulps are given in Tables 9 (Kottawa), 10 (Aththalapitiya) and 11 (Erabedde).

Comparison with commercial pulps

In order to assess the potential of these samples of *P. caribaea* as pulpwoods, the pulps were compared with pulps from a number of commercially used softwoods. All of these pulps had been prepared in the TPI laboratory using the same techniques as in the present investigation.

Properties of pulp from the nine-year old sample from Kottawa, with high tearing strength and moderate tensile and bursting strengths, most resembled those of pulp

Table 9

Sulphate pulp evaluation
Kottawa

Cook number	Kappa number	Beating rev.	Drainability CSF	Drainage time	Apparent density gcm^{-3}	Tensile index Nmg^{-1}	Stretch %	Tensile energy absorption index mJg^{-1}	Tear index mNm^2g^{-1}	Burst index $kPam^2g^{-1}$	Folding endurance	Air resistance s	ISO brightness %	Opacity %	Specific scattering coefficient cm^2g^{-1}
Unbleached															
MK571	53.4	0	760	4.4	0.34	27.4	1.2	225	10.3	0.920	1.11	0.1	15.5		
		1,430	745	4.5	0.50	49.3	2.1	722	17.0	2.63	2.58	0.2	12.0		
		4,290	690	4.6	0.55	64.4	2.8	1,180	18.2	3.82	2.84	0.4	10.5		
		7,150	540	4.7	0.57	72.8	2.9	1,450	17.1	4.78	2.96	2.0	10.5		
		10,010	405	4.8	0.58	76.3	3.0	1,620	16.8	5.04	2.98	8.0	10.0		
		12,870	238	5.4	0.60	84.5	3.0	1,710	15.7	5.36	2.98	63	10.0		
MK573	35.5	0	750	4.4	0.39	27.3	1.1	204	11.8	1.10	1.20	0.1	17.5		
		1,430	760	4.4	0.53	49.5	2.0	688	19.3	2.72	2.56	0.2	13.0		
		4,290	655	4.5	0.58	68.2	2.6	1,210	20.1	4.31	2.88	0.6	12.0		
		7,150	490	4.6	0.59	77.0	2.8	1,520	19.5	5.19	2.92	4.2	11.5		
		10,010	300	5.1	0.62	81.7	3.0	1,730	17.9	5.32	2.94	29	11.5		
		12,870	174	7.0	0.64	86.8	2.9	1,760	16.1	5.57	2.97	270	11.5		
MK575	26.5	0	750	4.4	0.40	31.1	1.2	251	13.1	1.21	1.26	0.1	20.0		
		1,430	740	4.4	0.54	49.3	2.0	664	19.0	2.63	2.45	0.2	15.0		
		4,290	620	4.6	0.59	67.6	2.6	1,240	17.7	4.16	2.86	1.0	13.5		
		7,150	415	4.8	0.61	77.0	2.8	1,480	16.1	4.82	2.90	9.8	13.0		
		10,010	222	6.2	0.64	83.0	2.8	1,620	15.2	5.14	2.93	120	13.5		
		12,870	112	11.9	0.67	88.3	2.9	1,820	13.8	5.63	2.87	over 1,000	13.0		
Bleached															
MK575		0	755	4.4	0.38	21.7	1.3	204	8.65	0.726	0.77	0.1	79.5	72.0	290
		1,430	730	4.4	0.56	45.7	2.3	734	17.7	2.49	2.35	0.3	74.5	65.0	200
		4,290	600	4.5	0.60	63.8	2.8	1,220	16.9	3.98	2.71	1.4	74.0	60.0	175
		5,720	490	4.6	0.62	69.7	3.0	1,430	15.8	4.49	2.81	5.8	73.5	59.5	165
		7,150	390	4.8	0.64	72.9	2.9	1,460	14.0	4.54	2.72	17	72.5	58.5	160
		8,580	285	5.4	0.65	74.5	3.1	1,610	14.0	4.78	2.73	60	72.5	57.0	155
		10,010	190	6.7	0.66	77.5	3.1	1,690	13.1	5.05	2.84	230	71.0	57.5	155

Table 10

Sulphate pulp evaluation
Aththalapitiya

Cook number	Kappa number	Beating rev.	Drainability CSF	Drainage time	Apparent density gcm^{-3}	Tensile index Nmg^{-1}	Stretch %	Tensile energy absorption index mJg^{-1}	Tear index mNm^2g^{-1}	Burst index $kPam^2g^{-1}$	Folding endurance	Air resistance s	ISO brightness %	Opacity %	Specific scattering coefficient cm^2g^{-1}
Unbleached															
MK596	55.0	0	760	4.4	0.36	31.6	1.0	210	11.1	1.08	1.30	0.1	16.0		
		1,430	750	4.4	0.50	55.4	2.0	798	17.1	3.01	2.64	0.2	12.0		
		4,290	705	4.6	0.53	74.9	2.5	1,290	17.1	4.69	2.84	0.4	11.0		
		7,150	590	4.6	0.56	82.0	2.8	1,590	16.0	5.30	2.90	1.4	10.5		
		10,010	440	4.9	0.58	87.8	3.0	1,820	15.4	5.92	2.98	6.8	10.0		
		12,870	300	5.2	0.59	89.5	3.3	2,010	14.5	6.10	2.98	34	10.0		
MK597	46.0	0	755	4.4	0.35	31.9	1.1	230	11.0	1.02	1.34	0.1	18.0		
		1,430	750	4.4	0.51	58.4	2.0	834	17.5	3.20	2.76	0.2	14.0		
		4,290	700	4.4	0.55	73.8	2.5	1,230	17.3	4.66	2.88	0.4	12.5		
		7,150	590	4.6	0.56	81.0	3.0	1,660	16.6	5.47	2.92	1.5	12.0		
		10,010	445	4.8	0.59	88.2	3.0	1,730	16.0	5.86	3.02	7.2	12.0		
		12,870	290	5.4	0.61	92.1	3.4	2,100	14.9	6.18	3.02	40	12.0		
MK587	41.8	0	760	4.4	0.38	34.5	1.1	271	11.3	1.30	1.47	0.1	18.5		
		1,430	745	4.5	0.51	59.0	1.9	766	17.2	3.18	2.77	0.2	14.0		
		4,290	690	4.5	0.56	77.0	2.6	1,350	17.4	4.54	2.92	0.6	12.5		
		7,150	550	4.6	0.57	84.8	2.7	1,570	17.1	5.60	2.94	1.5	12.0		
		10,010	410	4.8	0.57	92.4	2.8	1,710	15.8	6.24	2.98	8.4	12.0		
		12,870	290	5.4	0.60	92.5	3.0	1,880	15.5	6.11	3.05	42	12.0		
MK589	27.0	0	750	4.4	0.40	35.8	1.2	289	12.6	1.45	1.54	0.2	20.0		
		1,430	735	4.4	0.52	59.0	2.1	844	17.8	3.14	2.53	0.4	16.0		
		4,290	660	4.6	0.57	79.7	2.5	1,360	17.7	4.96	2.88	1.0	14.0		
		7,150	495	4.8	0.59	89.1	2.8	1,720	16.3	5.66	2.90	4.8	13.5		
		10,010	340	5.2	0.61	93.5	2.8	1,760	14.7	5.94	2.92	22	13.5		
		12,870	220	7.2	0.64	96.1	2.9	1,900	15.0	6.23	2.98	160	13.5		
MK591	21.1	0	750	4.5	0.40	34.8	1.2	268	12.0	1.30	1.42	0.2	23.0		
		1,430	730	4.5	0.53	57.7	1.9	750	18.7	3.02	2.54	0.4	18.0		
		4,290	645	4.5	0.59	76.8	2.4	1,250	17.3	4.66	2.74	0.9	16.5		
		7,150	470	4.8	0.60	85.6	2.7	1,540	16.2	5.56	2.86	6.3	16.0		
		10,010	300	5.8	0.62	94.0	2.8	1,730	15.3	5.96	2.88	45	16.0		
		12,870	168	11.6	0.64	94.9	2.8	1,840	14.2	6.08	2,96	340	16.0		
Bleached															
MK589		0	750	4.3	0.39	24.1	1.4	242	9.85	0.950	0.97	0.2	79.5	74.0	320
		1,430	725	4.4	0.55	58.2	2.4	961	17.1	3.02	2.53	0.5	76.0	67.0	225
		4,290	635	4.5	0.58	73.0	2.6	1,330	16.4	4.64	2.82	0.9	74.0	62.5	190
		7,150	480	5.0	0.61	83.1	2.8	1,600	15.1	5.50	2.90	5.0	73.0	60.5	175
		10,010	305	5.5	0.63	87.8	3.1	1,850	13.1	5.78	2.88	38	73.5	60.5	175
		12,870	200	7.7	0.68	85.4	3.4	1,960	12.2	5.67	3.00	310	73.0	59.5	160
MK591		0	745	4.4	0.39	24.1	1.3	230	9.36	0.813	0.82	0.2	78.0	75.0	330
		1,430	725	4.5	0.52	46.9	2.1	679	16.4	2.49	2.19	0.4	73.0	68.5	230
		4,290	590	4.6	0.58	70.3	2.7	1,320	14.9	4.29	2.70	1.8	71.0	65.5	195
		7,150	385	5.2	0.61	78.2	2.8	1,540	13.1	4.80	2.70	12	70.0	63.5	185
		10,010	164	9.6	0.65	85.8	2.8	1,670	12.1	5.30	2.82	220	69.0	64.5	180

Table 11

Sulphate pulp evaluation
Erabedde

Cook number	Kappa number	Beating rev.	Drainability CSF	Drainage time	Apparent density gcm^{-3}	Tensile index Nmg^{-1}	Stretch %	Tensile energy absorption index mJg^{-1}	Tear index mNm^2g^{-1}	Burst index $kPam^2g^{-1}$	Folding endurance	Air resistance s	ISO brightness %	Opacity %	Specific scattering coefficient cm^2g^{-1}
Unbleached															
MK593	56.2	0	750	4.3	0.40	39.5	1.5	405	16.8	2.06	2.45	0.2	16.5		
		1,430	745	4.4	0.54	61.8	2.3	995	19.7	3.88	3.04	0.4	13.5		
		4,290	715	4.5	0.60	84.5	2.8	1,660	16.2	5.74	3.16	1.0	11.5		
		7,150	645	4.5	0.62	98.0	3.0	2,000	14.8	6.80	3.16	2.3	10.5		
		10,010	560	4.6	0.64	91.5	3.1	1,950	14.1	6.77	3.19	7.1	10.0		
		12,870	390	4.9	0.65	102	3.3	2,270	13.5	7.50	3.22	35	10.0		
MK594	47.2	0	750	4.4	0.43	43.7	1.6	466	16.8	2.28	2.76	0.3	18.5		
		1,430	750	4.4	0.56	65.0	2.4	1,110	18.4	4.22	3.09	0.6	14.5		
		4,290	700	4.5	0.61	84.1	3.0	1,720	16.1	5.82	3.18	1.2	12.0		
		7,150	620	4.6	0.64	95.6	3.0	1,930	14.2	6.62	3.20	4.3	11.5		
		10,010	535	4.6	0.64	95.1	3.0	2,020	14.6	6.71	3.16	8.2	11.5		
		12,870	415	4.7	0.66	97.8	3.3	2,240	13.3	6.94	3.20	32	11.0		
MK579	44.7	0	750	4.4	0.40	38.6	1.4	382	14.2	1.84	2.05	0.2	18.0		
		1,430	735	4.5	0.56	66.9	2.6	1,150	20.0	4.10	3.10	0.6	14.5		
		4,290	690	4.6	0.61	90.4	2.9	1,730	16.3	5.70	3.14	1.3	12.5		
		7,150	610	4.7	0.63	99.4	3.0	1,950	14.4	6.51	3.18	3.7	11.5		
		10,010	505	4.8	0.64	98.4	3.1	2,070	14.3	6.87	3.19	11	11.0		
		12,870	390	4.9	0.66	103	3.2	2,170	12.9	7.15	3.22	40	11.0		
MK581	28.2	0	745	4.4	0.46	47.6	1.7	537	18.0	2.57	2.70	0.5	21.5		
		1,430	730	4.4	0.59	64.4	2.2	1,000	19.5	3.90	3.02	1.0	17.0		
		4,290	690	4.6	0.63	84.7	2.8	1,590	15.4	5.33	3.09	1.8	14.5		
		7,150	580	4.6	0.66	99.0	2.8	1,820	13.9	6.30	3.08	5.6	13.0		
		10,010	425	5.0	0.67	99.2	2.8	1,880	13.6	6.58	3.18	27	13.0		
		12,870	290	5.6	0.69	108	2.9	2,080	11.9	6.87	3.14	140	12.5		
MK583	22.6	0	735	4.5	0.46	40.7	1.8	530	17.8	2.28	2.66	0.6	23.5		
		1,430	730	4.5	0.59	59.4	2.3	994	18.6	3.67	3.08	1.0	19.0		
		4,290	660	4.6	0.63	80.8	2.7	1,580	15.5	5.04	3.06	2.4	16.5		
		7,150	540	4.8	0.66	89.3	2.8	1,740	13.6	5.78	3.14	8.6	15.0		
		10,010	370	5.2	0.68	92.1	2.8	1,810	11.7	5.98	3.10	72	14.5		
		12,870	224	6.8	0.70	112	2.8	1,960	12.0	6.48	3.19	480	14.5		
Bleached															
MK581		0	745	4.4	0.40	30.9	1.9	429	17.1	1.67	1.70	0.4	80.5	77.0	365
		1,430	735	4.4	0.58	53.0	2.8	1,060	20.2	3.29	2.91	1.0	75.5	70.5	250
		4,290	660	4.5	0.64	78.0	3.1	1,680	15.8	5.41	3.05	3.1	73.5	64.0	195
		7,150	560	4.6	0.66	83.2	3.3	1,870	13.6	5.62	3.06	6.3	72.0	61.5	170
		8,580	485	4.7	0.67	86.7	3.3	1,950	13.1	6.02	3.10	15	72.0	60.5	170
		10,010	410	4.8	0.69	94.1	3.1	2,010	11.6	6.25	3.01	49	71.0	59.0	160
		12,870	275	6.0	0.69	93.5	3.6	2,350	13.1	6.62	3.05	260	70.5	57.5	150
MK583		0	735	4.4	0.43	30.0	1.9	407	14.7	1.43	1.60	0.4	79.0	77.5	365
		1,430	710	4.6	0.59	55.1	2.6	1,030	16.4	3.08	2.67	1.0	74.0	72.0	255
		4,290	610	4.6	0.64	75.7	2.7	1,450	12.3	4.80	2.87	3.5	72.0	65.5	200
		5,720	490	4.8	0.66	77.7	2.9	1,570	10.7	4.86	2.87	15	71.5	65.0	200
		7,150	405	5.3	0.69	83.8	3.1	1,800	9.63	5.26	2.91	37	70.5	63.5	180
		10,010	218	7.2	0.72	87.3	3.2	1,940	9.50	5.61	2.89	630	69.0	61.0	165

Table 12

Bleaching conditions and bleached pulp evaluation

	Drainability CSF	Kottawa	Aththalapitiya		Erabedde	
Cook number		MK575	MK589	MK591	MK581	MK583
Yield, unbleached pulp* on oven dry wood, %		43.7	45.0	42.8	43.5	42.1
Kappa number of unbleached pulp		26.5	27.0	21.1	28.2	22.6
Bleaching conditions						
1 Chlorination for 1 h at 20°C; pulp consistency 3%						
Chlorine applied as Cl_2 on oven dry unbleached pulp, %		7.3	7.5	5.5	7.9	6.0
Chlorine consumed as Cl_2 on oven dry unbleached pulp, %		6.6	6.6	5.2	7.1	5.6
2 Alkali extraction for 1 h at 60°C; pulp consistency 6%						
NaOH on oven dry unbleached pulp, %		3	3	3	3	3
3 Hypochlorite for 2h at 35°C; pulp consistency 6%						
NaOCl as available Cl_2 on oven dry unbleached pulp, %		1.0	1.0	1.0	1.0	1.0
Available Cl_2 consumed on oven dry unbleached pulp, %		1.0	0.9	1.0	1.0	1.0
4 Chlorine dioxide for 3h at 70°C; pulp consistency 6%						
ClO_2 applied as Cl_2 equivalent on oven dry unbleached pulp, %		2.6	2.6	2.6	2.6	2.6
ClO_2 consumed as Cl_2 equivalent on oven dry unbleached pulp %		2.4	2.4	2.2	2.5	2.1
Total chlorine applied as Cl_2 on oven dry unbleached pulp, %		10.9	11.1	9.1	11.5	9.6
Total chlorine consumed as Cl_2 on oven dry unbleached pulp, %		9.9	9.9	8.3	10.6	8.6
Yield of pulp						
Oven dry bleached pulp on oven dry unbleached pulp, %		95.0	94.9	95.5	93.9	95.6
Oven dry bleached pulp on oven dry wood, %		41.6	42.7	40.9	40.9	40.2
Pulp evaluation						
ISO-brightness, unbeaten pulp, %		83.0	83.0	82.5	84.0	83.5
Specific scattering coefficient, unbeaten sheets, cm^2g^{-1}		290	320	330	365	365
Beating, rev.	500	5,580	6,860	5,720	8,290	5,720
	300	8,290	10,150	8,290	12,300	8,580
Apparent density, gcm^{-3}	500	0.62	0.61	0.60	0.68	0.67
	300	0.65	0.64	0.63	0.69	0.71
Tensile index, Nmg^{-1}	500	69.0	81.8	75.1	88.2	78.9
	300	75.0	86.9	82.6	94.0	87.2
Tear index, $kPam^2g^{-1}$	500	15.9	15.2	14.0	13.1	10.8
	300	13.8	13.2	12.7	12.2	9.35
Burst index, mNm^2g^{-1}	500	4.32	5.39	4.55	6.02	4.99
	300	4.80	5.75	5.10	6.46	5.49
Folding endurance	500	2.72	2.85	2.68	3.04	2.88
	300	2.79	2.94	2.79	3.08	2.92
Air resistance, s	500	4.5	4.5	4.3	12	14
	300	55	43	36	200	130
Opacity, %	500	59.0	61.5	64.5	60.5	64.0
	300	58.0	60.5	64.0	58.0	62.0
Specific scattering coefficient, cm^2g^{-1}	500	165	180	190	165	190
	300	155	170	185	150	170

Note:
* References to unbleached pulp in this table are to screened unbleached pulp

from Douglas Fir although the pulp from *P. caribaea* had better tearing strength and poorer tensile and bursting strengths. The twenty-year old sample from Aththalapitiya yielded pulp with slightly better overall characteristics than pulp from Southern pine. This indicates that both of these samples yielded pulps which should be useful in sack and packaging grades of paper. The sample from Erabedde was most like *P. taeda* and *P. patula* with good tensile and bursting strengths but with lower tearing strength.

The details of digestion conditions, pulp yields and pulp evaluation of the commercial woods are given in Table 13.

Table 13

Commercial coniferous softwoods
Unbleached sulphate pulp evaluations

	Drainability CSF	Douglas fir Western Canada		Southern pines Southern USA		*Pinus sylvestris* England			*Pinus taeda* Southern Africa		*Pinus patula* Southern Africa	
Cook number		MK46	MK45	MK95	MK94	MK83	MK59	MK24	MK311	MK312	MK309	MK310
Digestion conditions												
Active alkali as Na_2O on oven dry wood, %		17.5	20.0	17.5	20.0	15.0	17.5	20.0	17.5	20.0	17.5	20.0
Sulphidity, %		25	25	25	25	25	25	25	25	25	25	25
Liquor to oven dry wood ratio		5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1
Maximum temperature, °C		170	170	170	170	170	170	170	170	170	170	170
Time to reach maximum temperature, h		1	1	1	1	1	1	1	1	1	1	1
Time at maximum temperature, h		4	4	4	4	5	4	4	4	4	4	4
Chemical consumption												
Active alkali consumed as Na_2O on oven dry wood, %		13.8	14.6	12.7	13.5	12.5	13.6	14.0	13.0	13.7	13.6	14.2
Yield of pulp												
Yield of oven dry digested pulp on oven dry wood, %		42.1	40.0	45.5	43.7	48.6	47.0	43.8	44.0	41.5	44.1	41.7
Yield of oven dry screened pulp on oven dry wood, %		40.5	39.5	43.7	42.9	45.3	46.4	43.8	43.5	41.5	43.7	41.6
Yield of screenings on oven dry digested pulp, %		3.6	1.1	4.0	1.9	6.8	1.2	0.1	1.2	0.2	0.8	0.3
Pulp evaluation												
Kappa number		32.1	27.3	37.1	29.5	48.7	39.3	26.9	30.6	24.7	35.0	27.8
Beating, rev.	500	5,290	4,150	6,010	5,290	6,010	5,580	5,290	4,860	4,860	5,000	4,580
	300	8,290	7,150	9,720	9,150	9,720	8,870	8,580	8,010	8,290	8,010	7,720
Apparent density, gcm^{-3}	500	0.62	0.62	0.67	0.65	0.66	0.67	0.68	0.67	0.68	0.65	0.65
	300	0.65	0.65	0.68	0.68	0.69	0.69	0.71	0.69	0.71	0.68	0.68
Tensile index, Nmg^{-1}	500	86.5	85.5	84.9	81.5	104	103	101	97.5	93.5	103	96.5
	300	94.5	91.0	94.0	86.5	111	110	107	105	100	108	103
Tear index, mNm^2g^{-1}	500	18.3	17.5	15.4	14.9	15.1	13.7	13.6	12.3	11.9	13.3	12.6
	300	17.0	15.7	14.3	14.0	14.4	12.7	12.9	11.5	11.0	12.6	11.7
Burst index, $kPam^2g^{-1}$	500	6.05	5.75	5.65	5.55	7.25	7.15	6.70	6.75	6.15	6.85	6.25
	300	6.85	6.40	5.90	5.85	7.75	7.65	7.35	7.15	6.55	7.15	6.85
Folding endurance	500	3.14	3.07	2.97	2.94	3.14	3.14	3.05	3.05	3.00	3.03	3.00
	300	3.18	3.12	3.01	3.01	3.21	3.21	3.15	3.11	3.03	3.07	3.06
Air resistance, s	500	23	15	11	11	20	20	22	31	27	23	24
	300	120	100	120	110	200	140	200	220	250	220	210

If the three samples were used together, as is most likely to occur in practice, it is probable that the resulting pulp obtained would most resemble those from Douglas Fir or Southern pines. These pulpwoods are used widely to obtain pulps suitable for a wide range of packaging papers produced in fully integrated plants.

CONCLUSIONS

1. Three samples of *Pinus caribaea* from Sri Lanka were examined. One sample, aged nine years, was from a wet evergreen forest site; the other two, aged twenty years and twenty-two years, were from Montane forests.

2. The youngest sample had the highest density, the highest cellulose content and the lowest lignin content. These results were unexpected and it would appear that differences due to site conditions were so great that the expected changes with age were reversed. It would be necessary to examine samples of different ages from the same site to confirm this conclusion.

3. All samples were digested by the sulphate process to give unbleached screened pulp yields of about 45%.

4. The pulps from the youngest sample had the highest tearing strength and the lowest tensile and bursting strengths. Again, this was the opposite result to that expected but was consistent with all other determinations.

5. The pulps could be bleached by a chlorination, alkali-extraction, sodium hypochlorite and chlorine dioxide sequence to give bleached pulp yields of 40–43% at ISO-brightness of 82.5–84.

6. The best bleaching results were obtained when bleaching pulps with a kappa number of 25–30.

7. If the three samples were pulped together, they would be expected to yield pulps with properties similar to those of pulps from Douglas Fir and Southern pines and to produce packaging grades of paper in integrated mills.

8. The pulps from *P. caribaea* could be mixed with straw pulp to improve the tearing strength of paper. This applies especially to pulp from the Kottawa sample which had the highest tearing strength.

REFERENCES

FAO (1981) Projected Pulp and Paper Mill in the World 1980–1990. Rome: Food and Agriculture Organization of the United Nations. 132pp.

PALMER, E. R. and GIBBS, J. A. (1971) Pulping characteristics of nine year old *Pinus caribaea* from Sabah. *Report of the Tropical Products Institute.* L25, iv + 37pp.

PALMER, E. R. and GIBBS, J. A. (1972) The pulping characteristics of *Pinus caribaea* from the main growing areas in Fiji, 1971. *Report of the Tropical Products Institute.* L27, iv + 60pp.

PALMER, E. R. and GIBBS, J. A. (1976) Pulping characteristics of *Pinus caribaea* from Belize. *Report of the Tropical Products Institute.* L43, iv + 43pp.

PPI (1981) Annual review. *Pulp and Paper International,* **23** (8), 109.

RYDHOLM, S. A. (1965) Pulping Processes. New York and London: Interscience Publishers. ix + 1269pp.

Appendix

EXPERIMENTAL METHODS IN PULPING INVESTIGATIONS

1. Apparent density of wood

One disc, approximately 20mm thick was prepared from each log cut at the stated percentage heights of the tree. The green volume was determined by weighing the disc, which had been soaked in water until it was saturated, immersed in water. It was then dried to constant weight at 105 ± 3°C to obtain its oven dry weight. The apparent density in kgm^{-3} was calculated from:

$$\frac{\text{oven dry weight (g)} \times 1{,}000}{\text{green (soaked) volume (cm}^3\text{)}}$$

2. Bark content

The volumetric value was obtained by measuring the overbark (g_o) and underbark (g_u) girths of a log as received and calculating the content from:

$$\frac{(g_o{}^2 - g_u{}^2) \times 100}{g_o{}^2}$$

The gravimetric value was determined by drying and weighing the bark from a measured length of log at 105 ± 3°C. The dry weight of the wood (log minus bark) was calculated from its volume and apparent density. The percentage bark weight was calculated from:

$$\frac{\text{weight of bark} \times 100}{\text{weight of bark} + \text{weight of wood}}$$

3. Chemical analysis

A portion of the chips prepared for pulping was ground in an Apex knife mill. Chemical analyses were made on groundwood which passed a 425μm aperture sieve. For some analyses where the presence of fine material interferes with analysis, the groundwood was further sieved and the fines passing a 250μm aperture sieve discarded. For some analyses an extractive-free sample of groundwood was prepared by successive treatment with alcohol-benzene, alcohol and hot water as described in TAPPI Standard, T12. Some or all of the analyses listed in Table A, using the standards or methods indicated, were undertaken:

Table A

Chemical analysis of groundwood

Analysis	TAPPI Standard or method used	With or without fines	Extractive free
Hot and cold water solubility	T207	Without	No
1% sodium hydroxide solubility	T212	With	No
Alcohol-benzene extractives	T204	Without	No
Alcohol extractives		Without	No[1]
Total extractives[2]	T12	Without	No[3]
Ash	T211	With	No
Silica (acid insoluble ash)	T244	With	No
Acid insoluble lignin	T222	With	Yes
Pentosans	T223	Without	Yes
Holocellulose	Wise *et al.* (1946)	Without	Yes
Alpha-cellulose	T203[4]	Without	Yes[5]

Notes:

1. Uses material remaining after alcohol-benzene extraction
2. Residue obtained by evaporation of successive alcohol-benzene, alcohol and hot water extracts
3. Uses material remaining after alcohol extraction
4. Modified for gravimetric determination
5. Uses material obtained in holocellulose determination

4. Fibre measurements

(a) *By microscopy:* Fibre measurements were made on re-dispersions of pieces of standard sheets made from unbeaten sulphate pulp and they are thus representative of a composite sample. The fibres were mounted in aqueous medium and the length, width and wall thickness of 400 fibres measured. The lengths of all fibre elements both whole and broken, the width of the partially collapsed fibres and the wall thickness were determined by measurements of the projected image. For length a magnification of X 45 was used and for width and wall thickness X 800. Because pulping and pressing during sheet making causes the fibres to collapse, the widths are typical of the pulp only. Fibre wall thickness as measured may also differ from that observed on a cross-section of wood.

(b) *By classification:* The fibre length by classification was determined using a McNett classifier and weighing after oven drying, the fibres retained on each screen. In previous work the average length of the fibres on each screen had been determined by measurement of the projected image of 100 fibres. These values, given in Table B were used to calculated the weighted average fibre length in the sample.

Table B

Fibre length by classification

Passes aperture, μm	–	1,680	1,190	841*	595	420	210	74
Retained on aperture, μm	1,680	1,190	841	595	420	210	74	–
Assigned length softwoods, mm	3.8	3.2	2.5	2.1	1.7	1.2	0.65	0.3
Assigned length hardwoods, mm	–	–	–	1.15	1.0	0.92	0.68	0.3

Note:
* Not for hardwoods

5. Pulping methods

The sample used for pulping was prepared by taking the same number of approximately 20mm thick discs from all logs representing the sample. The discs were split along the grain with a mechanical guillotine to give a chip size approximately 20 X 20 X 6mm. This damages the fibres less than commercial chipping. If necessary the chips were air dried until the moisture content was less than 12% and then mixed to give a representative sample. In the Kraft (sulphate) process the active chemicals are sodium hydroxide and sodium sulphide, the concentrations of which were calculated using the definitions:

Active alkali = $NaOH + Na_2S$ expressed as % Na_2O on oven dry wood

$$\text{Sulphidity} = \frac{Na_2S \times 100}{NaOH + Na_2S} \quad \text{all compounds expressed as \% } Na_2O$$

A sulphidity of 25% was used in all digestions. The authors' experience and published work show there to be generally little variation in pulp quality with changes in sulphidity between 20 and 30%. Digestions were made in a stainless steel pressure vessel with forced circulation and an electric heat exchanger. The cooked chips were washed free of superficial black liquor and broken up in a propeller type disintegrator to simulate the disintegration occuring during blowing in a commercial digester; the pulp was screened using a plate with 0.15mm wide slits, to remove shive and collected on a 106μm aperture sieve. The yield of pulp was determined by drying the whole of the screened pulp in a stream of air to about 10% moisture. The total weight of air dry screened pulp and the moisture content of an aliquot were determined for calculating the yield of oven dry pulp. The shive was also collected, dried and weighed. The chemical consumption was determined by titrating with standard hydrochloric acid (i) an ashed aliquot of the black liquor to determine total alkali and (ii) an aliquot of the black liquor from which the reaction products of digestion had been removed by precipitation with barium chloride to determine the residual active alkali.

6. Unbleached pulp evaluation

Experience in the TPI laboratory has shown that pulp, air dried as above, can be stored for long periods with little change in strength characteristics. These were lower however when compared with a similar slush pulp when unbeaten, but little difference was found when the two pulps were beaten. The kappa number was determined by TAPPI method, T236. In this method the amount of permanganate consumed by pulp under specified conditions was measured and, for pulp yields of less than 70%, the percentage of Klason lignin is given approximately by kappa number $\times$ 0.15. The physical characteristics of the pulp were determined by preparing sheets from the air dried pulp over a range of beating points using a British sheet machine which had been modified for semi-automatic operation. The sheets were then tested after conditioning at 23±1°C and 50±2% relative humidity. Sheets made in this way were essentially the same as sheets prepared according to the proposals of the 'Second Report of the Pulp Evaluation Committee to the Technical Section of the (British) Papermakers' Association' (1936). The methods used for the physical examination of the stock and sheets, based on the above report and current International Standards Organisation and British standards, were as follows:

(a) *Beating:* 24g (oven dry basis) portions of air dried pulp were dispersed in 2 litres of water in a disintegrator for 75,000 revolutions. The pulps were then beaten for a range of different numbers of revolutions of the beater roll in a PFI mill using a consistency of 10%. The beating pressure was 3.33Nmm^{-1} of bar length for softwoods and 1.77Nmm^{-1} of bar length for hardwoods. The rotational frequency of the beater roll was 24.9s^{-1} (unloaded) and the differential peripheral speed of the beating elements 2ms^{-1}.

(b) *Drainability (Canadian standard freeness):* The beaten pulp was dispersed in 2 litres of water in a disintegrator for 7,500 revolutions. This was then diluted to give a final stock volume of 8 litres. The drainability (Canadian standard freeness) is an empirical measure of the rate at which water will separate from one litre of this 0.3% stock at 20°C through a standard perforated plate, in apparatus calibrated by the Pulp and Paper Research Institute of Canada.

(c) *Drainage time:* The drainage time was determined on the standard sheet machine during normal sheetmaking operations. It is the time in seconds for water at 20°C to flow from the pulp suspension through the wire from a height 350mm above the wire until the formed sheet is no longer immersed.

(d) *Grammage (gm $^{-2}$):* Determined by weighing a fixed area after standard conditioning and after drying to constant weight at 105 ± 3°C.

(e) *Bulking thickness (μm):* Ten sheets were placed one on top of the other and their thickness measured at ten points located using template described in TAPPI Standard T220 with a dead weight (50kPa pressure) motor driven micrometer. The thickness of one sheet in μm was calculated.

(f) *Apparent density (gcm^{-3}):* Obtained by dividing the grammage (gm^{-2}) by the bulking thickness (μm) of a single sheet.

(g) *Tensile index (Nmg^{-1}), stretch (%) and tensile energy absorption index (mJg^{-1}):* Determined using a semi-automatic horizontal instrument with a constant rate of elongation. Ten strips, 15mm wide, were tested with the jaws initially 90mm apart.

(h) *Tear index (mNm^2 g^{-1}):* Determined using one of two instruments:

(i) A single tear standard Elmendorf tear tester. Normally four test pieces were torn at one time through a distance of 43mm. Normally eight tears were made.

(ii) A double tear Marx-Elmendorf tear tester. Normally three test pieces were torn at one time in two places through a distance of 44mm. Sheets with high tearing strength were torn either in pairs or singly in order to obtain a reading on the central portion of the scale. Normally four tears (readings) were made.

(i) *Burst index (kPam^2 g^{-1}):* Eighteen tests were made using a Frank Schopper-Dalen type pneumatic burst tester.

(j) *Folding endurance:* A test strip, 15mm wide and under a load of 7.85N was folded through 312° until it ruptured using a Kohler-Molin type instrument. The number of double folds for each of eight strips was recorded. The mean of the logarithms (base 10) of the number of double folds for each individual test was calculated to give the folding endurance.

(k) *Printing roughness (μm):* Determined using a Parker Print-Surf instrument with an input pressure of 0.63m water gauge and a lower clamp backing of neoprene (soft). The clamping pressure was 20kgfcm^{-2}. Five tests were made on each of the rough and smooth sides of the sheets.

(l) *Air resistance (s):* Eight sheets were tested using a closed top Gurley densometer with a 577g inner cylinder. The time for 100cm^3 of air to pass through 6.45cm^2 of sheet was measured by an automatic timing attachment.

(m) *ISO-brightness (%) (diffuse blue reflecting factor):* Determined using a Carl Zeiss Elrepho reflection photometer having a filter with an effective maximum transmission wavelength of 457nm. The instrument reading is the ratio of the radiation reflected by a pad of sheets, thick enough to be opaque, to that reflected by a perfect reflecting diffuser under the same conditions. Five readings were made on the rough sides of the sheets.

Tests (e) to (m) were carried out in a standard atmosphere of 23.0 ± 1.0°C and 50.0 ± 2.0% relative humidity. In all of the tests except folding endurance, a mean instrument reading was obtained from the replicates tested. This was then used to calculate the property value. Results obtained by the methods described would be expected to give similar results to those that would be obtained by using TAPPI Standards T205 (Forming handsheets) and T220 (Physical testing).

7. Bleaching and bleached pulp evaluation

Bleaching trials were made by a four stage method involving successive applications of chlorine, sodium hydroxide, sodium hypochlorite and chlorine dioxide (CEHD). This is the simplest sequence currently used to obtain a fully bleached sulphate pulp. The quantity of chlorine added, sufficient to give an excess that would not be consumed within the reaction time, was estimated from the kappa number using data, previously obtained, on the relationship between kappa number and chlorine demand. The bleached pulp evaluation was carried out as described under *Section 6, Unbleached pulp evaluation,* with the following additional tests:

(a) *Opacity (%):* Determined using a Carl Zeiss Elrepho reflection photometer having a CIE tristimulus value Y filter. The reflectance (R_o) from a single sheet over a black background and the reflectance (R_∞) from a pad of sheets sufficiently thick enough to be opaque, were measured for ten and five sheets respectively. The opacity was calculated from:

$$\text{Opacity} = \frac{R_o \times 100}{R_\infty}$$

(b) *Specific scattering coefficient ($cm^2 g^{-1}$):* Calculated according to the method of Giertz (1950). The Kubelka-Munk relationship between the opacity ($\frac{R_o}{R_\infty}$) and the reflectance (R_∞) (both determined above) enables the scattering power (SX) to be calculated. The specific scattering coefficient (s) is then obtained from:

$$s = \frac{SX}{W}$$

where W is the grammage in gcm^{-2}.

(c) *ISO-brightness (%) unbeaten pulp:* Four test sheets of approximately $200gm^{-2}$ grammage (2g oven dry weight per sheet) were prepared according to BS 4432 Part 4: 1975 (ISO 3688). Prior to the introduction of this standard, three sheets weighing between 2 and 3g each were prepared on a standard British Sheet machine (*see* Section 6) using de-ionised water. The sheets were then tested within 4h of their drying by measurement of the ISO-brightness (*see* Section 6 (m)).

It should be noted that in tables for bleached pulp giving values for ISO-brightness for a range of beating points, there is given a beating point of zero revolutions. Although this is for unbeaten pulp, it is a value for a normal $60gm^{-2}$ grammage sheet prepared and tested by methods given in Section 6 and should not be confused with the test given above for *'ISO-brightness, unbeaten pulp'* and titled as such in the tables.

REFERENCES

BRITISH PAPERMAKERS' ASSOCIATION (1936) Second report of the Pulp Evaluation Committee. London: BPMA, 168pp.

BRITISH STANDARDS INSTITUTION. British Standards. London: BSI.

GIERTZ, H. W. (1950) Opaciteten hos pappermassor. *Svensk Papperstidning,* **53**, 673–680.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. ISO Standards. Geneva, Switzerland: ISO.

TECHNICAL ASSOCIATION OF THE PULP AND PAPER INDUSTRY. TAPPI Standards: Official, provisional and useful test methods. Atlanta, USA: TAPPI.

WISE, L. E., MURPHY, M. and D'ADDIECO, A. A. (1946) Chlorite hollocellulose, its fractionation and bearing on summative wood analysis and studies on the hemicelluloses. *Paper Trade J.,* **122** (2), 35–43.

Printed in England for Her Majesty's Stationery Office by Hobbs the Printers of Southampton
(77) Dd8293491 K10 4/82 G3927