Pulping of Tropical Pines Strength Properties vis-a-vis Chemical Composition

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SUMMARY

The present study deals with the strength evaluation of sulphate pulps of tropical pines, grown in Araku Valley and the probable improvement in strength characteristics by blending the pulps with bamboo pulps. Sulphate pulping of stem and branch wood components of five individual pine species (viz. *Pinus caribaea* (Honduras), *P. greggii* (Mexico); *P. Kesiya* (K & J Hills); *P. oocarpa* var. *ochoterenai* and *P. patula* (Mexico) have been carried out and strength characteristics of both unbleached and bleached pulps have been evaluated at 40° SR freeness. The branch wood component, although present in minor quantities (8-10% on the whole tree) were found to be inferior in quality with respect to their pulp yield, chemical requirement and strength properties to the stem wood component of the species. Amongst of *P. kesiya* and *P. oocarpa* were found to be of superior quality in terms of strength, yield, chemical requirement and strength characteristics.

The improvement in strength properties, except tear factor, of the blended pulps was quite encouraging.

The strength properties of the pulps have been analysed in terms of its chemical composition.

INTRODUCTION

By the end of Fifth and Sixth Five Year Plans, the indigenous production of paper and boards will have to be sufficiently increased to the tune of 1.5 million tonnes and 2 million tonnes respectively as against the present installed capacity of 0.8 to 0.9 million tonnes. To meet such a growing demand fore more paper and dwindling supply of conventional raw materials for paper making, it has become a necessity to exploit the alternate non conventional raw material like tropical hardwoods and agricultural residues. Continuous attempts are being made to utilize the tropical hardwoods to produce acceptable qualities of paper for successful blending of the same with that of bamboo pulps without affecting much the strength characteristics of paper. The short fibered nature of the pulp obtained from mixed tropical wood has been the main limitation for it to act as a substitute for bamboo pulp. India's resources of long fibered mateiials other than bamboo are considerably limited. To solve this problem of raw material shortage, trial production of fast growing pine wood species using short-rotation forestry (SRF) management techniques have been successfully undertaken in some areas of West Bengal, Himachal Pradesh, Uttar Pradesh, Andhra Pradesh etc. Number of tropical pines have been grown on trial basis at Araku Valley and Maredumilli of Andhra Pradesh since 1964 and the result of the trial have given hope that the commercial pine plantation will be feasible in the region. The following are of the pine species which have been grown on trial plot preferably over 500 metres altitude :

P. caribaea.	(Hondurıas)
P. greggii.	(Mexico)
P. kesiya.	(K & J Hills)
P. oocarpa.	(Ochoterenai)
P. patula.	(Mexico)

The characteristics of these pine trees and details connected with their growth have been previously described.[1,2] The tropical pines are reported to be capable of yielding over 150 tonnes of air-dry pulp wood per hectare at the end of a 15-year rotation.

Pulping studies have been undertaken on these different species of tropical pines, grown in Araku Valley, Andhra Pradesh, to evaluate their pulpability and other characteristics of these pulps.

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This paper describes the detailed studies conducted to throw light on pulping characteristics of stem wood and branch wood of five different pine species, grown in Araku Valley. The strength properties are examined in terms of fiber morphology and the chemical composition of the pulps.

EXPERIMENTAL

500 Kgs. billets of five diffeient pine species consisting of stem wood and branch woods separately, were received from the pine research station at Araku Valley and Maredumilli. The above mentioned species were tested in the laboratory for their pulpability and compared with that of bamboo (*Dendrocalamus strictus*) and *Pinus roxburghii* (25 years old) of Himalayan region. Debarked wood samples weie chipped in a five-knife wigger chipper of the chipper house and screened in vibratory screens. Knots, bark and other impurities were then removed from each chip sample. The chips from each component were thoroughly blended and moisture contents were determined prior to cooking.

Wood dust of the individual species passing through 40 mesh and ietained on 60 mesh was used for proximate analysis, employing Tappi Standard Methods. The result of the analysis are presented in Table–IIa.

All digestions were made in a 35 litre, electrically heated rotary digester, using the white liquor of sulphidity 15–17% and material to liquor ratio of 1:2.8. The chips (containing 80–90% in the range 5–35mm in grain direction) were cooked at different cooking conditions so as to obtain pulps of high and low permanganate number for packaging and bleachable varieties, respectively, as mentioned below :

(1) Cooking with 16% active alkali (as Na_2O on oven dry chip basis) to a temperature of 174°C 2½ hours (including time to raise to 175°C). Under these conditions stem and branch woods of these pine species were cooked individually, to obtain pulps of high Kappa number. (2) Cooking with 17 and 17.5% active alkali (as Na_2O) for a period of 3 hours (including steaming peiiod of 1½ hours) to obtain pulps of low Kappa number (31–37).

Maintaining these conditions, pulping of mixture of pines as well as individual pine species, were cariied out. At the end of the digestion, the spent liquors were analysed for residual alkali. The pulps were washed free of cooking liquor in the centrifugal hydro extractor to a consistency of 28–30 percent, and screened yield of the pulp was computed. Kappa numbers of the unbleached pulps were determined according to Tappi Standards, and the permanganate numbers of all these conifer species were calculated as per the modified equations, specified in Tappi[3]. The pulping data are recorded in Tables— III & IX.

Screened pulps were then beaten to 40°SR freeness in a Valley beater and standard sheets of 60 gsm were made and dried in air using rings and plates. The sheets were conditioned at 50±2 R.H. and 23±2°C and evaluated for their tensile strength, bursting strength, tearing resistance, folding endurance, density and opacity (scattering coefficient) according to Tappi methods (T220 m-60 and T425 m-60). The results are furnished in Tables—IV & IX.

In all cases, unbleached pine pulps, beaten to 40°SR, were mixed with bamboo-hardwood blend (65%+35%) beaten to 40°SR separately, in proportions 20%+80% and 30%+70% and strength properties of the resultant blend were evaluated. The results are presented in Tables—V & VI.

BLEACHING OF PULP

Representative sample of granulated unbleached pulps were taken and bleached by C-E-H Sequence (Chlorination, alkali extraction and hypochlorite), using requisite chlorine, depending on the Kappa number of the pulp to obtain brightness value 77–80 percent based on Standard MgO. The bleached pulp was then tested for yield, brightness and cupriethylene diamine viscosity (0.5%). The results of bleaching of pulps are recorded in Tables–VII & X.

The bleached pulps were then beaten to 40°SR in the Valley beater and hand sheets of 60 gsm were made. The pulp evaluation results are presented in Tables—VII and X.

The results of fiber measurements and their deiived values made on samples of these species are furnished in Table—XI.

DISCUSSION OF RESULTS

In Tables—II to IV, the chemical and physical characteristics of young tropical pines are compared with *D. strictus* and Himalayan pine (*P. roxburghii*) proximate analysis of tropical pines, as presented in Table–IIA show that these species have lower ash contents (0.3 to 0.8%), lower solubilities of cold water, hot water and 1% alkali and lower pentosan content, as compared to that of bamboo. Comparatively higher Klason lignin content found in these pine species result in relatively difficult pulping, as shown by higher kappa number (50–70) of the pulp when the same amount of alkali (Active Alkali) was used for bamboo and pines.

Lowei beating rates of pine wood pulps, as shown by longer beating time to beat to a desired freeness (40°SR) may be explained by lower pentosan content (xylans) and polyuronides.

However, when one compares the strength properties of the pulp vis-a-vis their chemical composition certain interesting facts emerge. The fact that bamboo pulps and hard wood pulps have higher pentosan content, than pine wood pulps and yet do not exhibit greater strength characteristics point out that hemicelluloses of pine woods may contain more of glucomannan than hardwoods or bamboo in which xylan predominates[4].

It is pertinent to point out here that the strength of the paper is not derived purely from frictional forces in an entanglement of fibers and fibrils, but the main interfiber cohesion arises from hydrogen bonds developed between the hydroxyl groups of the carbohydrates in adjacent fibers. The effectiveness of the hemicelluloses is believed to be due to the fact that hemicelluloses have a shorter chain length and are more hydrophillic as a result, "wet" better and produce a stronger bond when derived in contact with adjascent fiber surfaces.

The fact that the hemicellulose function as a binder through the mutual bonding of their hydroxyl groups (through inter molecular hydrogen bonding) has been demonstrated by Aiken(5). It is also interesting to note that the softwood hemicellulose is much more effective in fiber bonding than hard wood hemicelluloses and this has been attributed to the mannose and other hexose content(6). The greater bonding effect of mannan over xylan is mainly attiibuted to the availability of more hydroxyl groups per unit chain, and to the fact that the additional hydroxyl being a primary type, possess greater mobility, thereby keeping down the confoımational requirements. Such increased inter fiber bonding facilitated by the hemicelluloses by their marked contribution to the inter molecular hydrogen bonding naturally enhances the strength characteristics of paper connected to the strength of inter fiber bonding, viz. bursting strength, tensile strength.

It has also been suggested in literature(7a) that bursting strength of bleached wood pulps can be correlated with the gamma cellulose content. It has further been pointed out the amount of alkali soluble hemicellulose is more responsible for the strength properties than the pentosan content of the pulp and also the alkali extractable hemicellulose content is more indicative than the total hemicellulose content(7b). This conclusion has been arrived at from the studies involving aspen bleached kraft and "modified holocellulose" which had the same xylan content but different total alkali extractable hemicelluloses. A perusal of our data, however shows that this may not be the case always. Thus even though bamboo (*D. strictus*) has nearly the same gamma cellulose content and higher pentosans than pine wood species, the stiength characteristics of bamboo exhibit lower values.

However no appreciable increase in tear strength is noticed when the strength properties are compared with that of bamboo. This can be attributed to the fact that, the tearing strength applies a stress of local character and depends on the structural element present, like the fiber length. Thus bamboo and tropical pines which do not differ much in fiber length do not differ much in tear factoı. Again this is an over approximation and has to be treated with some reservation.

There have also been instances in literature where hemicelluloses adversely affect the strength of structural element and thence the tearing strength(8,9). This is to be traced to the fact that increased eohesion in sheet tends to concentrate the tearing forch in a small area instead of permitting it to diffuse over wide path. Thus the gluco-mannan and other hemicelluloses which promote the interfiber bonding, as reflected in higher bursting and tensile strengths has no beneficial effect on tearing strength, and in fact in some cases bring down the tear factor.

In this connection it is also worth while to compare our ıesults on 12 years old tropical pines with those of Kirk and coworkers who have investigated the pulping of 12 years old Lobolly pines (10). They have found that these young tropical pines (12-13 years age), exhibit higher tensile stıength, bursting strength, folding endurance, but lower tear. They have attributed such differences in the properties, as observed, to the presence of more juvenile wood which is mainly in young trees (12–15 years) and in tops and centres of the older trees.

Differences in strength characteristics between tropical pines of Araku Valley and *Pinus roxburghii* of Himalayan region (25 years old) are illustrated in Table—IV. It should be noted that this old pine exhibits high tear factor and this has higher fibre length.

STEM WOOD AND BRANCH WOOD OF TROPICAL PINES

The physical and chemical properties of stem and branch woods of these pine species are compared in Tables—II, III, IV, VII, VIII and IX.

Branch wood of the pine species contained higher levels of lignin, ash extractive than that of their corresponding stem wood species. Branches of pines consume more active alkali than stem wood of the same species. To obtain a Kappa number of 31 ± 1 (K. No. 21) at constant 'H' Factor higher chemical charge as percentage Na_2O on dry chips, has been used for branch wood pulps. Under identical conditions of temperature and time, an active alkali charge of 17.5% (as Na_2O) has been made in the case of branch wood mixture as against the chemical requirement of 17.0% as Na_2O for stem wood mixture (vide Table—IX).

Comparing at the same Kappa number of pulp, branch wood mixture resulted in lower pulp yield than that of stem wood (Branch wood mixture yielded 36.6% as against the pulp yield of 42.2% for stem woods at Kappa number 31 ± 1).

Of all the pine species, stem and branch woods of *P. caribaea* (*Honduras*) and *P. greggii* (*Mexico*) are characterised by their higher chemical consumption to obtain pulps of same Kappa number (31–37) and slightly inferior strength characteristics as compared to the other pine wood specis(viz. *P. kesiya, P.oocarpa* and *P. patula*) vide Tables—IX and X.

When they were cooked under identical conditions (16% Active Alkali as Na_2O, 2½ hours at 174°C), *P. caribaea* and *P. greggii* (stem as well as branch woods) resulted in lower screened yield, higher rejects, higher Kappa number of pulp and lower pulps strength especially breaking length, density, folding endurance and tear factor (Table-VII). Further, bleaching of these wood pulps show that these species (*P. caribaea* and *P. greggii*) consume more of bleaching chemicals to achieve a brightness level of 77–80 percent Elrepho. The viscosity and strength of these pulps were inferior to other varieties. Further more, mixture of pine species (branches or stem woods) resulted in lower screened yield, lower Kappa number and inferior strength properties of pulp, as compared to that of individual pine wood species (Table—III).

Among all the pine species, *P. kesiya* and *P. oocarpa* resulted in pulps of high quality with regard to pulp yield, bleach consumption and strength properties.

It can be observed from Tables–V and VI that strength characteristics, except tear factor, can be improved to a considerable extent by blending pine wood pulps with bamboo hardwood pulp blend.

Lower values of beating time and strength properties of the sheets, as observed for branch wood pulps, may be attributed to the shorter fiber length of branch wood relative to stem wood of the same species. The higher beating rate of branch wood pulps is a result of lower cohesion of the fiber walls. Hatton et., al [11] attributes this to the high galactan content in branch wood which promotes swelling. Relatively low mean pulp yield obtained from the branch wood is partially accounted for by high lignin content. EINSPHAR [12] accounts for the reduced yield and lower strength of branch wood pulps to the high levels of compression wood. Superior strength properties of *P. kesiya* might be attributable to the highest sheet density and lower scattering coefficient of the sheet.

FIBER MORPHOLOGY AND RELATED PROPERTIES

In comparing the physical properties of pine wood pulps with each other and with bamboo pulp, however, the use of fiber dimensions, as given in Table–XI, to account for the differences should be related with reservations. It seems, therefore, practicable to compare the fiber morphology of these pines as a group with that of bamboo strictus. The bamboos of A.P. Origin have a narrow range of flexibility coefficient (lumen diameter/fiber diameter) 0.33–0.38, while tropical pines have higher coefficient (0.51–0.79), as compared to bamboo indicate that the fibers collapse or flatten more easily, resulting better bonding when beaten, to produce higher burst, tensile and fold values. However, the lower flexibility coefficient values observed for *P. kesiya, P. oocarpa* and *P. patula* (0.513–0.64) as against coefficient values (0.709–0.76) for other two species can not explain the higher characteristics of these pulps.

The fiber dimensions of *P. caribaea* and *P. greggii* are almost comparable in all respects, showing the similarity in their physical properties.

Branch wood components possess shorter, thinner wall tracheids with lower Runkel coefficient indicating poor tearing strength of these pulps. Higher tearing strength of sheets made from *P. kesiya, P. oocarpa* and *P. patula* can be explained by their longer and thicker walled tracheids and higher Runkel ratio (twice the wall thickness/lumen diameter : 2 w/l [13-14])

TABLE—I

TROPICAL PINE SPECIES AND THEIR BASIC DENSITIES

Name of the species			Basic density (Green volume) Tons/M^3
1.	**P. caribaea**	(Honduras)	
A_1		Stem wood	0.291
A_2		Branch wood	0.383
2.	**P. greggii**	(Maxico)	
B_1		Stem wood	0.284
B_2		Branch wood	0.357
3.	**P. kesiya**	(K & J Hills)	
C_1		Stem wood	0.263
C_2		Branch wood	0.315
4.	**P. oocarpa**	(Ochoterenai)	
D_1		Stem wood	0.253
D_2		Branch wood	0.291
5.	**P. patula**	(Mexico)	
E_1		Stem wood	0.282
E_2		Branch wood	0.328

CONCLUSIONS

1. Tropical pine woods produced from short-rotation forestry operation (12-15 years)result in pulps having higher bursting strength, tensile strength and folding strength but lower tearing strength with easy beating qualities than that of the pulp produced from older and slower gowing trees viz. *P. roxburghii* Because of their superior strength characteristics pines produced under short rotation forestry can replace the bamboo in the longer run.

2. The unbleached pulps of high Kappa number can be successfully blended with bamboo hardwood blended pulp, to produce strong kraft paper

TABLE—II A

PROXIMATE ANALYSIS OF PINES AND BAMBOO

Sl. No.	Particulars		Tropical Pines (Stem Wood)					Tropical pines stem wood mixture	Tropical pines branch wood mixture	Bamboo (Dendrocalamus strictus) (APPM)
			A_1	B_1	C_1	D_1	E_1			
1.	Ash,	%	0.3	0.58	0.65	0.41	0.28	0.7	1.7	3.7
2.	Hot water solubility,	%	6.2	3.47	4.90	2.01	2.1	3.6	6.3	—
3.	1% NaOH solubility,	%	10.3	4.9	8.00	8.6	7.49	7.65	8.35	19.0
4.	Alcohol-Benzene solubility,	%	2.59	5.72	2.52	4.93	1.39	2.5	3.51	2.6
5.	Pentosans,	%	8.30	6.68	9.35	7.70	6.43	9.20	8.80	16.3–17.2
6.	Holocellulose*,	%	62.91	61.32	69.50	67.55	69.74	69.20	59.50	65.1–67.0
7.	Klason Lignin*,	%	28.80	28.9	22.90	25.68	27.10	26.80	29.87	25.0–27.0

* Ash corrected.

TABLE—II B

POLYSACCHARIDE CONTENTS OF BLEACHED PINE WOOD AND BAMBOO PULPS

Sl. No.	Particulars		Pinus kesiya		Pinus oocarpa	Pinus caribaea	Bamboo
			Stem wood pulp	Branch wood pulp	Stem wood pulp	Stem wood pulp	D. strictus pulp (A.P.P.M.)
1.	Alpha Cellulose,	%	80.3	80.60	79.16	82.26	75.54
2.	Beta Cellulose,	%	3.50	1.82	7.65	6.59	4.53
3.	Gamma Cellulose,	%	11.65	15.10	10.38	9.16	12.0
4.	Pentosans,	%	7.08	10.10	7.67	8.90	11 6

TABLE—III

COOKING DETAILS OF STEM AND BRANCH WOODS OF TROPICAL PINES

Sl. No.	Particulars	P. caribaea		P. greggii		P. kesiya		P. oocarpa		P. patula		Stem wood Mixture of Pines	Branch wood Mixtures of Pines	Himalayan Pine P. roxburghii	Dendrocalamus strictus (APPM)
		A1	A2	B1	B2	C1	C2	D1	D2	E1	E2				
1.	Active Alkali as Na_2O, % (on O.D. Chips)	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	18.0	16.0
2.	Bath Ratio	1:2.8	1:2.8	1:2.8	1:2.8	1:2.8	1:2.8	1:2.8	1:2.8	1:2.8	1:2.8	1:2.8	1:2.8	1:3	1:2.8
3.	Time to Max. Temp., Mts.	90	90	90	90	90	90	90	90	90	90	90	90	90	90
4.	Time at Max. Temp., Mts.	60	60	60	60	60	60	60	60	60	60	60	60	60	60
5.	Max. Temperature, °C	174	174	174	174	174	174	174	174	174	174	174	174	170	165
6.	Screened Pulp Yield, %	41.6	35.3	46.0	41.8	46.0	44.5	47.6	42.23	46.3	43.1	43.8	42.9	42.2	48.8
7.	Screenings, %	3.5	7.9	2.3	5.3	3.0	1.50	2.60	2.2	2.8	1.7	3.0	3.0	0.4	1.0
8.	Residual Active Alkali as Na_2O, %	2.8	2.3	2.0	2.2	2.4	2.8	2.9	1.8	3.0	2.2	2.3	1.6	2.2	1.8
9.	Kappa Number	60.4	74.6	70.1	70.2	43.0	59.2	51.4	58.9	48.1	55.2	43.0	51.1	—	—
10.	Permanganate Number (40 ml)	32.5	—	35.1	35.1	26.6	32.2	29.8	32.1	28.6	31.0	26.6	29.7	29.4	24.2

TABLE—IV

EVALUATION OF UNBLEACHED PINE WOOD PULPS

Sl. No.	Particulars		P. caribaea A$_1$	P. caribaea A$_2$	P. greggii B$_1$	P. greggii B$_2$	P. kesiya C$_1$	P. kesiya C$_2$	P. oocarpa D$_1$	P. oocarpa D$_2$	P. patula E$_1$	P. patula E$_2$	Stem wood mixture	Branch wood mixture	Himalayan pine P. roxburghii	Dendrocalamus strictus (APPM)
1.	Initial Freeness,	°SR	10	10	10	10	10	10	10	10	10	10	10	10	9	16
2.	Final Freeness,	°SR	40	40	40	41	40	40	40	40	41	42	40	40	40	40
3.	Beating Time,	Mts.	58	32	59	34.5	37	33	47	31	51	30	39	30	70	23
4.	STRENGTH PROPERTIES															
a.	Sheet density,	gm/cc	0.68	0.65	0.74	0.67	0.83	0.78	0.71	0.70	0.69	0.68	0.7353	0.7161	0.635	0.57
b.	Breaking Length,	Mtrs.	7700	7200	8100	7800	8840	8000	9650	8400	8500	8100	8300	7900	6500	6100
c.	Tear Factor		70	61	78	73	94	82	103	76	105	87	70	61	140	93
d.	Folding Endurance		190	214	343	220	704	282	350	296	350	290	292	127	344	63
e.	Burst Factor		44	46	58	56	57	61	66	55	57	55	48	46	42	34
f.	Strength Index (*)		1915	1871	2254	2124	2481	2306	2585	2179	2498	2277	1876	1805	2462	1786

(*) Strength Index = 100 x (Burst factor x Tear Factor x Log Fold)1/3.

TABLE—V

EFFECT OF BLENDING OF PINE PULPS (STEMWOOD) WITH BAMBOO+HARDWOOD KRAFT PULP ON STRENGTH PROPERTIES

Sl. No.	Particulars	A$_1$			B$_1$		C$_1$			D$_1$			E$_1$		
		B+W	(B+W) +P	(B+W) +P	B+W	(B+W) +P	B+W	(B+W) +P	(B+W) +P	B+W	(B+W) +P	(B+W) +P	B+W	(B+W) +P	(B+W) +P
		65%+ 35%	80%+ 20%	70%+ 30%	65%+ 35%	80%+ 20%	65%+ 35%	80%+ 20%	70%+ 30%	65%+ 35%	80%+ 20%	70%+ 30%	65%+ 35%	70%+ 30%	80%+ 20%
1.	Breaking Length (Metres)	5900	6900	7500	5900	6700	5900	7000	7000	5900	7100	7400	5900	6600	7200
2.	Burst Factor	37	39	40	32	36	32	37	37	37	42	43	37	40	41
3.	Tear Factor	85	85	85	85	90	85	93	93	85	97	98	85	102	90
4.	Folding Endurance	103	91	116	45	152	45	168	215	103	171	193	103	242	173

TABLE—VI

EFFECT OF BLENDING OF BRANCH WOOD PULPS WITH BAMBOO+HARDWOOD BLEND

Sl. No.	Particulars	A_2			B_2			C_2			D_2			E_2		
		B+W	(B+W) +P	B+W +P	B+W	(B+W) +P	B+W +P	(B+W)	(B+W) +P	B+W +P	B+W	(B+W) +P	B+W +P	(B+W)	(B+W) +P	B+W +P
		65%+ 35%	80%+ 20%	70%+ 30%	65%+ 35%	80%+ 20%	70%+ 30%	65%+ 35%	80%+ 20%	70%+ 30%	65%+ 35%	80%+ 20%	70%+ 30%	65%+ 35%	80%+ 20%	70%+ 30%
1.	Breaking Length (Metres)	5600	6030	6200	5250	6200	6330	5250	6200	6300	5600	6750	6900	5600	6140	6500
2.	Burst Factor	35	39	41	32	37	38	32	40	41	35	38	40	35	38	39
3.	Tear Factor	78	82	82	87	89	83	87	87	85	78	87	86	78	78	78
4.	Folding Endurance	52	68	121	31	81	100	31	99	168	52	110	194	52	112	139

TABLE—VIII

EVALUATION OF BLEACHED PULPS

Sl No.	Particulars		A_1	A_2	B_1	B_2	C_1	C_2	D_1	D_2	E_1	E_2	Stem wood mixture	Branch wood mixture	Bamboo D. strictus (APPM)
1.	Initial Freeness,	°SR	10	10	10	11	10	11	10	11	10	10	10	10	18
2.	Final Freeness,	°SR	40	41	42	41	42	41	41	41	41	40	40	40	40
3.	Beating Time,	Mts.	25.5	21	25	19	25.5	19	23	19	25.5	19	22.5	18	12
4.	**Strength Properties**														
a.	Breaking Length,	Mtrs.	7700	7700	7600	6300	8200	7650	9200	7500	7700	7600	7200	7760	5560
b.	Burst Factor		49	51	53	44	58	56	51	49	57	50	52	42	35
c.	Folding Endurance		151	44	137	4	200	61	211	33	267	40	126	15	11
d.	Tear Factor		59	56	51	49	78	60	70	51	75	58	60	51	75

TABLE—VII

BLEACHING OF STEM AND BRANCH WOOD—UNBLEACHED PULPS

Sl. No.	Particulars	P. caribaea		P. greggii		P. kesiya		P. oocarpa		P. patula		Stem wood Mixture	Branch wood Mixture
		A_1	A_2	B_1	B_2	C_1	C_2	D_1	D_2	E_1	E_2		
1.	Kappa Number	60.4	74.6	70.1	70.2	43.0	59.2	58.9	51.4	48.1	55.2	43.0	51.1
2.	Chlorine Added as Gas, %	10.0	13.0	13.0	13.0	8.0	12.0	12.0	12.0	10.0	12.0	9.0	12.0
3.	Chlorine consumed, %	9.96	12.9	12.8	12.6	7.9	11.9	11.6	11.4	9.9	11.6	8.67	11.0
4.	Alkali added, %	3.5	4.0	3.5	4.0	3.0	4.0	3.5	4.0	3.5	4.0	3.0	4.0
5.	Alkali consumed, %	3.42	3.36	3.46	3.7	2.9	3.0	3.26	3.25	3.26	3.26	2.62	3.04
6.	Chlorine added as Hypo, %	5.0	6.0	6.0	6.0	4.0	5.0	4.0	4.5	4.0	4.0	4.0	3.5
7.	Hypo consumed, %	4.8	5.9	5.55	5.7	3.65	4.86	3.63	4.04	3.86	3.65	3.60	3.13
8.	Buffer added to maintain pH 8–9.5, %	1.10	0.91	1.00	1.00	1.26	1.00	1.00	1.00	1.00	1.00	1.00	1.00
9.	Final Brightness, Elrepho Units	70.5	78.3	80.0	80.0	76.5	76.0	80.5	77.0	77.0	79.0	78.0	79.0
10.	Viscosity of Pulp, Cps.	11.0	5.0	7.8	6.0	8.8	6.93	8.2	6.4	12.1	6.43	7.1	5.3
11.	Bleached pulp yield, on O.D. Chips, %	39.81	34.15	42.78	39.29	44.60	42.27	43.79	38.84	41.89	39.13	42.75	40.33

	Cy. %	Temp. °C	Time Mts.	pH
Chlorine Stage (C)	3.00	Ambient	60	1.8– 2.2
Alkali Stage (E)	10.00	60 ± 2	90	10.8–11.2
Hypo Stage (H)	8.00	38 ± 2	120	8.5– 9.5

TABLE—IX

PULPING OF STEM AND BRANCH WOOD MIXTURE

Sl. No.	Particulars	P. caribaea 90% Stem + 10% Branches	P. greggii 90% Stem + 10% Branches	P. kesiya 90% Stem + 10% Branches	P. oocarpa 90% Stem + 10% Branches	P. patula 90% Stem + 10% Branches	Stem wood Mixture	Branch wood Mixture
1.	Active Alkali as Na_2O, % (on O.D. Chips)	17.5	17.5	17.0	17.0	17.0	17.0	17.5
2.	Bath Ratio	1:2.8	1:2.8	1:2.8	1:2.8	1:2.8	1:2.8	1:2.8
3.	Time to Max. Temp., Mts.	90	90	90	90	90	90	90
4.	Time at Max. Temp., Mts.	90	90	90	90	90	90	90
5.	Maximum Temp., °C	174	174	174	174	174	174	174
6.	Screened Pulp Yield, %	41.0	41.8	45.4	42.6	42.2	42.2	36.7
7.	Scıeenings, %	1.7	1.0	0.85	2.5	0.8	0.2	1.0
8.	Residual Active Alkali as Na_2O, %	0.62	0.15	1.7	1.7	1.3	2.4	1.86
9.	Kappa Number	35.7	31.8	36.3	35.8	32.6	31.03	30.6
10.	Permanganate Number	23.5	21.6	23.8	23.6	22.0	21.1	20.8
11.	**Pulp Evaluation**							
	Initial Freeness, °SR	9	9	9	9	9	9	9
	Final Freeness, °SR	40	40	40	40	40	40	40
	Beating Time, Mts.	25	27	29.5	32	24	32	29
	Breaking Length, Metres	7300	7980	7800	8100	7500	6900	6600
	Burst Factor	46	50	54	54	49	49	46
	Tear Factor	62	72	99	88	96	93	57
	Folding Endurance	163	254	544	593	325	333	204

TABLE—X

BLEACHING OF UNBLEACHED PULPS OF LOW KAPPA NUMBER

Sl. No.	Particulars	P. caribaea 90% Stem + 10% Branches	P. greggii 90% Stem + 10% Branches	P. kesiya 90% Stem + 10% Branches	P. oocarpa 90% Stem + 10% Branches	P. patula 90% Stem + 10% Branches	Tropical Pines Stem wood Mixture	Tropical Pines Stem wood Mixture
1.	Kappa Number	35.7	31.8	36.3	35.8	32.6	31.03	30.6
2.	Chlorine as Gas, %	6.0	6.0	6.0	6.0	6.0	6.0	6.0
3.	Chlorine consumed, %	5.95	5.89	5.82	5.8	5.64	5.84	5.88
4.	Alkali added, %	3.0	2.50	3.0	2.5	2.50	2.5	2.5
5.	Alkali consumed, %	2.3	2.30	2.65	2.35	1.9	2.15	2.20
6.	Chlorine as Hypo, %	3.5	2.50	3.0	3.0	2.5	2.5	2.5
7.	Hypo consumed, %	3.27	2.23	2.82	2.82	2.1	2.15	2.28
8.	Buffer added, %	1.00	0.68	0.75	0.80	0.75	0.80	0.76
9.	Brightness of pulp, Elrepho units	78.5	80.0	80.0	79.0	78.5	79.0	78.5
10.	0.5% C.E.D. Viscosity, Cps	6.55	6.5	7.53	6.84	5.0	7.62	5.2
11.	Bleached Pulp yield, % (on o.d. chips)	38.0	36.25	42.23	40.28	39.25	39.03	34.2
12.	**Pulp Evaluation**							
	a) Initial freeness, °SR	11	12	11	11	11	11	12
	b) Final Freeness, °SR	40	40	41	40	41	40	40
	c) Beating Time, minutes	23	22.5	20	18	21	19	17
	d) Sheet Density, g/cc	0.666	0.701	0.817	0.781	0.73	0.732	0.712
	e) Breaking Length, Metres	7110	6100	7700	7875	7030	7200	6500
	f) Burst Factor	47	46	52	49	47	46	36
	g) Folding Endurance, Nos.	12	15	65	71	29	62	27
	h) Tear Factor	58	56	74	64	59	71	46
13.	Specific Scattering Coefficient (Cm^2/gm)	271.6	251.2	194	222.4	213.2	227	242

TABLE—XI

FIBER DIMENSIONS AND THEIR DERIVED VALUES

Code No	Particulars		L mm	d μ	l μ	W μ	L/d	2W/l	l/d
A1	**P.carribaea**	(Stem wood)	2.255	41.5	29.6	6.0	54.36	0.4054	0.7099
A_2	-do-	(Branches)	1.982	39.3	27.7	5.8	50.52	0.4180	0.7050
B_1	**P.greggii**	(Stem wood)	2.290	40.7	29.0	5.85	56.26	0.4052	0.7125
B_2	-do-	(Branches)	2.238	35.8	27.4	4.2	62.53	0.3066	0.7650
Cl	**P. kesiya**	(Stem wood)	2.324	38.5	22.75	7.87	60.36	0.6929	0.5909
C_2	-do-	(Branches)	2.132	34.5	21.80	6.35	61.80	0.5830	0.6320
D_1	**P. oocarpa**	(Stem wood)	2.516	55.0	30.0	12.50	45.44	0.8330	0.5954
D_2	-do-	(Branches)	2.317	36.3	22.7	6.80	63.80	0.5990	0.6253
E_1	**P. patula**	(Stem wood)	2.274	44.0	22.6	10.70	57.68	0.9468	0.5130
E_2	-do-	(Branches)	2.207	38.7	25.0	6.85	57.00	0.5480	0.6460
	Dendrocalamus strictus (APPM Variety)		2.085	18.5	6.70	5.90	112.60	1.7610	0.3620
	Pinus roxburghii		3.230	28.0	——	——	115.00	——	——

L — Average fiber length

d — Fiber diameter

l — Lumen diameter

w — Cell Wall thickness

L/d — Felting Coefficient

2W/l — Runkle Coefficient

l/d — Flexibility Coefficient

3. Branch wood pulps of these pine species are found to be inferior in strength properties to that of stem wood component of the same species. Further because of high lignin content of the branches, they consume more of cooking chemicals, so as to produce a reasonable permanaganate number of the pulp. At the same permangante number of the pulp (20–21), the mean pulp yield of branch wood was found to be lower than that of stem woods.

4. Among the species, the branch and stem wood species of *P. caribaea* and *P. greggii* resulted in lower

csreened yield, higher permanganate number and inferior strength characteristics of the pulp.

5. Of all the tropical species, *P. kesiya* and *P. oocarpa* were found to produce pulps of superior quality.

6. The increased strength characteristics related to inter fiber bonding can be accounted for in terms of increased inter molecular hydrogen bonding facilitated by the hemicelluloses, probably gluco-mannon.

ACKNOWLEDGEMENTS

The authors are thankful to the management of The Andhra Pradesh Paper Mills Ltd., Rajahmundry, for the permission to publish this work. They are particularly indebted to Mr. M.P. Maheshwari, Works Manager and Mr. D.N. Jakate, Dy. Works Manager for their keen interest and constant encouragement in this work and for many valuable discussions.

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