Investigation on thermo mechanical pulping of some fast growing species

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SUMMARY

The thermomechanical pulping process has not been fully established for indigenous hardwoods and nonwood plant fibres, due to diversity in celluler ultrastructure as compared to softwoods. Central Pulp & Paper Research Institute with its versatile TMP unit had initiated studies on TMP and CTMP pulps from indigenous raw materials. In the present investigations a comparative study, on thermomechanical and chemithermomechanical pulping of fast growing species like *Albegia falcataria,* kenaf and eta reed, has been made. Detailed investigations, on the influence of different process variables like consistency, preheating temperature, chip moisture and plate pattern on strength development of eta reed TMP were carried out. In all the cases yield of TMP was more than 95% with an initial brightness of over 40%. The pulps were clean. The CTMP pulp and lower yield (92%) but had good strength properties. In the batch trials eta reed TMP produced at preheating temperature of 120°C had better strength properties compared to those of the pulps produced at 130°C and 110°C. However in large scale trials, clogging of dams of refining zone with pulp was observed which impaired strength development. Etareed TMP showed satisfactory runnability on the paper machine. *A. falcatiaria* TMP and CTMP pulps were easily bleached to 60% brightness with 15% and 9% hypo respectively. Peroxide bleaching was more effective than hypochlorite bleaching. Eta reed TMP even with 20% hypo chlorite showed only 4 units of brightness development, indicating poor bleaching response to hypochlorite.

The specific energy consumption was dependent on chip size and production rate of the pulp Studies conducted indicate that by maintaining optimum process variables it is possible to produce TMP pulps of improved strength properties from these raw materials.

Today there is a growing trend of the implication for the expanded use of thermomechanical and other type of refiner mechanical pulps for the manufacture of newsprint and other grades of paper. This is considered important in terms of resource conservation, full-forest utilization, power demands, over all impact on the environment and product quality. A recent survey of literature on thermomechanical pulping indicated that the world production of TMP has reached upto 5496 admt/d, 85% of which is being utilized for newsprint manufacture[1]. The process technology for TMP of softwoods has been fully established and efforts are being made to recover the heat in the TMP process which required higher energy inputs as compared to RMP and GW processes. Suitability of indigenous raw materials, which includes hardwoods, agricultural residues, bamboo and reeds, for thermomechanical pulping has not been investigated thoroughly. Preliminary investigations carried out on hardwoods showed that stronger pulps could not be produced from these raw materials mainly because of the diversity in cellular ultrastructure as compared to softwoods, and recommended CTMP process. Matsuo, R. et al[2] have shown that newsprint grade CTMP pulp, could be produced from bagasse. They have discussed effect of different variables in the process, like plate pattern, chemical treatment and energy inputs. Experiments conducted on hardwoods and nonwood plant fibres reveal that CTMP process would be suitable for these raw materials[3]. However before we look forward to CTMP, modified TMP and other refiner mechanical pulping processes,

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it is necessary to investigate the influence of different process variables on efficient separation and refining of the fibers in TMP process for our raw materials. The process variables in TMP process like raw material quality, preheating temperature, dwell time, consistency, energy input and plate pattern have to be optimised from the view point of higher production rate, low energy inputs and better quality pulps.

Central Pulp & Paper Research Institute with its Deffbrator TMP pilot plant had initiated studies in this direction. In the earlier studies reported[4], thermomechanical and chemithermomechanical pulping of indigenous softwoods like spruce, pine & hardwoods like encalyptus, were investigated. At the present juncture with limited supply of tropical conifers, it would be necessary to explore the possibility of producing TMP and CTMP from all those major indigenous fibrous raw materials. More efforts are needed to develop optimum process conditions for producing cost-effective and better quality pulps which can replace chemical grade pulps in newsprint manufacture. In the present studies thermomechanical pulping of three fast growing fibrous raw materials viz eta reed, *A begia* falcateria and kenaf, was investigated.

Results and discussions

Raw material quality : All the three raw materials possessed different basic and bulk densities. (Table-1). Moisture uptake increased with decreased density of the chips Kenaf and *A. falcataria* had lower densities compared to eta reed The chip moisture is important aspect in TMP as lignin softening temperature decreases with increased moisture content[6]. All the three raw materials produced TMP pulps of more than 95% yield (Table-2). *A. falcataria* CTMP pulp had lower yield, (92.3%) and both the TMP and CTMP pulps had higher brightness as compared to eta reed TMP pulp Kenaf produced TMP pulp with brigntness as high as 49 4%. The production rate was lower for *A. falcataria* due to low bulk density. Kenaf and *A. falcataria* required higher energy inputs due to lower production rates. Eta reed required lower energy inputs. For kenaf higher disc clearance was sufficient to achieve freeness of 150 ml (CSF).

Table-3 shows that eta reed TMP had better strength properties. Kenaf had lower strength properties which was presumably due to higher fines content as indicated by fiber classification.

Fines might be presumably from pithy material, *A. falcataria* CTMP possesssd good strength properties more than two folds as compared to TMP and had lower amount of fines content. However the specific scattering coefficient was lower in the case of CTMP. All the TMP pulps had low screen rejects indicating complete fibre separation. Photo micrograph 3 and 4 show that *A. falcataria* had shorter fibers. SEM photomicrograph-7 of TMP sheet shows that there was no fibrillation and showed poor flexibility. Photomicrograph-1 of eta reed TMP fibre at 120°C shows flexible long fibres with little fibrillation.

TABLE – 1. RAW MATERIAL DATA

Raw material	Basic density* kg/m³	Bulk density** kg/m³	Moisture uptake on over night soaking %
Albegia falcataria	230	102	74.0
Eta reed	600	233	48.6
Kenaf	330	147	64.0

* Green volume/OD weight

** Expressed on moisture free basis.

Poor fibrillation shows that in secondary stage the energy input has not been utilized efficiently in refining Sumi. Y. etal[7] have established that 67-80% of the total energy input should be utilized in secondary refining as the energy required in break down of chips into single fibers in primary refining is low. Thus for better utilization of energy, plate pattern with larger area of perfect refining zone may be necessary. All the TMP pulps had strength properties higher than salai ground wood pulps.

Environmental aspects : Pollution loads from TMP and CTMP pulping in given in Table-4.

1. Etareed TMP (120°c)

TABLE—2. REFINING CONDITIONS FOR TMP AND CTMP OF DIFFERENT RAW MATERIAL

Pulp produced	Pressurized primary refining				Atmospheric secondary refining				Pulp yield	Free-ness** CSF	Bright-ness	Screen rejects
	Produc-tion rate	Pre-heater temp.	Plate clear-ance	Specific energy consum-ption*	Tempe-rature	Plate clear-ance	Specific energy consum-ption*	Total sp. energy consumed				
	kg/h	°C	mm	kwh/t		°C	kwh/t	kwh/t	%	ml	%	%
A. falcataria TMP	48.4	120	0.4	1839	90	0.2	1115	2954	95.8	480	44.5	0 72
A. falcataria CTMP	46.6	119	0.4	1416	87	0.2	1008	2424	92.3	470	44.4	0.07
Kenaf	93.0	121	0.5	1050	85	0.3	590	1640	96.2	150	49.4	1.10
Ete reed TMP	111.5	121	0.4	618	84	0.2	474	1092	96.7	450	41.2	1.60
Eta reed TMP	111.0	128	0.4	644	87	0.2	481	1125	95.6	260	41.5	1.30
Eta reed TMP	111.4	110	0.4	642	81	0.2	510	1152	96.3	210	42.6	0.60
Eta reed TMP	88.0	120	0.35	852	82	0.2	795	1647	—	110	—	—

(Large scale trial)

* Idling losses are not included

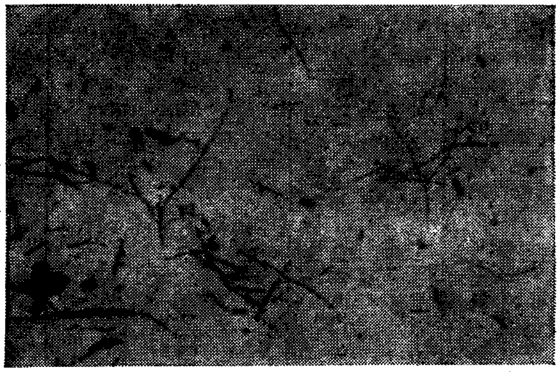
** Freeness values are after pulp latency removal.

TABLE—3. STRENGTH PROPERTIES OF TMP PULPS FROM DIFFERENT RAW MATERIALS

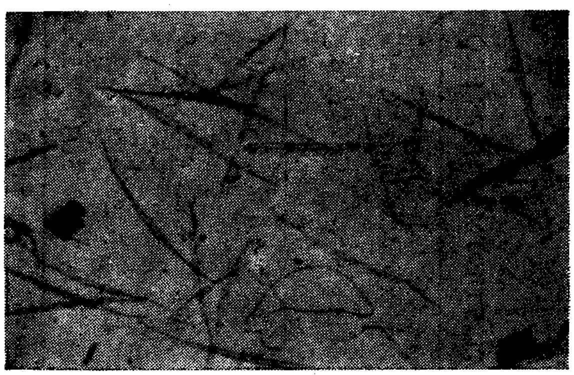
Pulp	Free-ness* CSF ml	Drain-age time (s)	Appa-rent density g/cm³	Burst index kPa. m²/g	Tensile index N m/g	Tear index mN-m²/g	Brigh tness %	Sp. Scatt Coeff. m²/kg	Wet web IWWT index Nm/g	ITEA index mNm/g	Fiber classification (Bauer McNett) R28	P28/R48	P48/R100	P100/R200	P200
Albegia falcataria TMP	210	4 69	0.48	0.25	15.0	2.0	44.6	50.0	0.32	6.6	25.3	28.2	6.6	17.6	22.3
Albegia falcataria CTMP	240	5.20	0.67	1.65	36.5	4.35	42.2	38.9	0.67	12.0	23.4	36.3	2.5	13.7	17.1
Eta reed	105	7.23	0.46	0.45	17.5	3.49	41.1	42.5	0.28	14.0	29.7	19.8	9.7	15.7	25 1
Kenaf	105	4.07	0.35	(1)	7.7	1.50	51.3	52.0	0.19	5.0	15.7	10.7	17.1	17.3	39.2

* After post refining in PFI Mill.

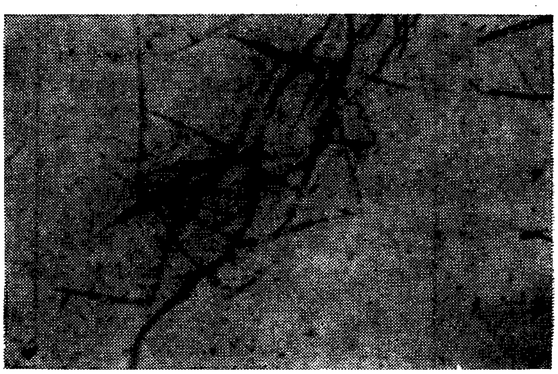
(1) Too low to be measured.



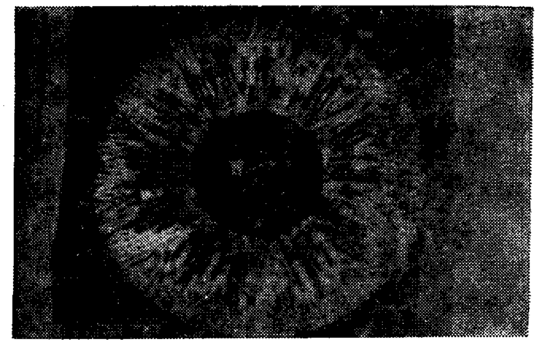
2. Etareed TMP (Continuous)



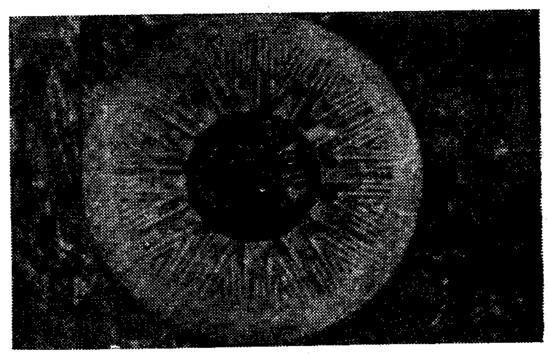
3. A. Falcataria TMP



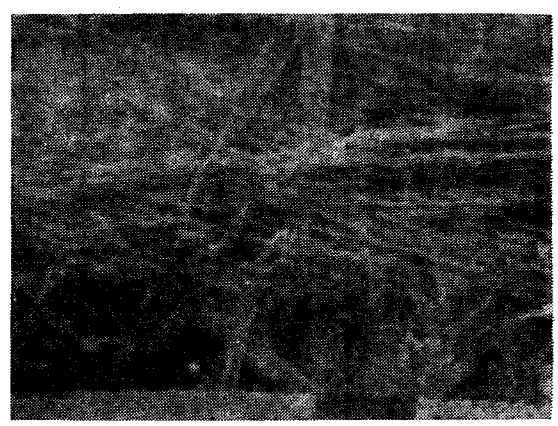
4. A. Falcataria CTMP



5. Pulp clogged refiner plate first stage



6. Pulp clogged refiner plate second stage



7. SEM. Photomicrograph of
A. falcataria sheet.

TABLE—4. POLLUTION LOADS* IN THERMO MECHANICAL PULPING

Pulp	Dissolved solids	Suspended solids	COD
A. falcataria TMP	31.0	6.4	51.0
A. falcataria CTMP	72.0	9.4	99.0
Eta reed TMP	43 6	10.2	40.0
Kenaf TMP	37.5	11.5	46.0

*Expressed as kg/odt pulp.

The TMP process produces effluents with slightly higher pollution load as compared to GW process. COD load of TMP effluents from different raw materials is on higher side as compared to the values 27-35 kg. COD/t, reported for softwood TMP effluents[7]. *A. falcataria* CTMP produced effluents with two times COD load more than TMP process.

However the pollution loads could be minimized by maximum recycling of fiberizing liquor and washings.

Effect of preheating temperature

Generally accepted rationals for operating near glass transition point concerns the greater ease of fibre separation as the wood temperature is increased to this level[8]. The preheating temperature is one of the important process variables which can have influence on fiber properties The effect of preheating temperature on strength properties of TMP pulps have been discussed[9,10,11,12]. The strength properties of TMP pulps of eta reed produced at different preheating temperatures showed wide variation Table-5.

The TMP pulp produced at 120°C preheating temperature had higher strength properties and fiber fractions as compared to those of the pulps produced at 110 and 128°C. The pulps produced at 110 and 128°C had higher fines content (P. 200 fraction) arising from cutting of fibers. The temperature higher than 120°C indicates that the glass transition point must have passed leaving brittle fibers coated with lignin. The variation in temperature did not have significant effect on energy requirement, brightness and scattering coefficient. Thus it is important to maintain the preheating temperature below glass transition where maximum lignin softening could be achieved.

Effect of plate pattern and clearance on strength development

Disc pattern is the most important machine variable. The disc pattern chosen must allow operation with high energy inputs at safe disc clearances. Number of articles are published on the effect of plate pattern in thermo-mechanical pulping[2,13,14]. Matsuo etal[2] have shown that plate pattern was important variable in bagasse chemithermomechanical pulping. The strength development and energy reduction was achieved by using pattern with a larger area of perfect refining zone. Tyler A.G., etal[13] have confirmed that plate pattern determines the maximum throughput attainable and the stability of the motor load.

The importance of plate pattern was keenly felt during the large scale trials of eta reed TMP where unlike the batch trials the large scale TMP trial produced pulp of inferior strength properties with lower production rate Table-2. At the end of the trial it was noticed that rotor and stator plates of both the refiners were severely clogged with the pulp, which resulted both in extensive fiber cutting and lower intake of raw material. Photographs 5 and 6 show the clogged plates. Photo micrograph-2. shows the TMP pulp fibers from large scale trial containing more debris.

In batch trials the clogging was not much Table-6 shows the effect of plate pattern and clearance on strength development in TMP process.

In this trial the plate pattern 5811 in secondary refiner was replaced by 5821 which had coarser perfect refining zone. Both the plate patterns had three zones, coarse. middle and perfect. The strength development was poor with latter plate pattern. The tear index and wet web strength were dropped indicating cutting of fibres. In case of 5811 decreased plate clearance lowered the strengths of pulp, while in case of 5821 strength improvement was observed. It is necessary to study thoroughly on different plate patterns, for different raw materials

It appears that the plates with larger area and finer structure of perfect refining zone might be ideal for our raw materials. Thus it would be necessary to select appropriate plate pattern with safe disc clearances.

Effect of consistency : In TMP process high refining consistency facilitates high energy inputs without using too narrow disc clearance there by avoiding fibre cutting. High consistency has also an advantage from the view point of the heat recovery. In the present TMP trials the consistencies in primary and secondary refining varied between 12-18% which

TABLE—5. COMPARISON OF STRENGTH PROPERTIES OF ETA REED THERMOMECHANICAL PULPS PRODUCED AT DIFFERENT PREHEATING TEMPERATURES

Pre heater temperature °C	Specific energy consumption kwh/t	Freeness CSF ml	Drainage time (s)	Apparent density g/cm³	Burst index kPa.m²/g	Tensile index N.m/g	Tear index mNm²/g	IWWT index Nm/g	Brightness %	Sp. Scatt. Coeff. m²/kg	Fiber classification (Bauer McNett) R28	P28/R48	P48/R100	P100/R200	P200
110	1152	100	6.36	0.39	0.15	8.10	2.50	0.24	42.0	45.5	23.4	14.5	9.4	21.8	30 9
121	1092	105	7.23	0.46	0.45	17.5	3.49	0.28	41.1	42.5	29.7	19.8	9.7	15.7	25.1
128	1125	110	6.55	0.40	0.20	12.0	3.25	0.26	42.1	46.4	28.6	13.7	9.9	18.6	29.2

TABLE—6. INFLUENCE OF PLATE PATTERN AND CLEARANCE ON STRENGTH PROPERTIES OF ETA REED TMP PULPS

Ist stage refining		IInd stage refining		Pulp Properties						Wet web properties	
Plate pattern	Clearance mm	Plate pattern	Clearance mm	Freeness CSF ml	Apparent density g/cm³	Drainage time (s)	Burst index kPa m²/g	Tensile index N.m/g	Tear index Mn.m²/g	IWWT index Nm/g	ITEA index mNm/g
R >5821 S	0.4	R >5811 S	0.2	405	0.44	4.39	0.15	13.0	3.50	0.40	15
	0.3		0.2	110	0.39	6.83	(1)	9.0	2.05	0.28	14
R >5821 S	0.4	R >5821 S	0.15	85	0.36	5.44	(1)	6.0	1.40	0.18	6
	0.4		0.2	210	0.32	4.0	(1)	6.0	1.75	0.19	10
	0.5		0.2	365	0.32	3.63	(1)	4.8	2.05	0.16	7

R — Rotor Preheating temperature — 118—120°C
S — Stator Dwell time — 4 mins
(1) Too low to be measured.

TABLE -7 INFLUENCE OF CONSISTENCY ON STRENGTH PROPERTIES OF ETAREED TMP PULPS

Pulp consistency %	PFI (rev.)	Freeness CSF ml	Drainage time (s)	Apparent density g/cm³	Burst index KPa. m²/g	Tensile index N.m/g	Tear index mN. m²/g	P200 fraction	Wet web IWWT index Nm/g	Wet web ITEA index mN.m/g
—	0	260	4.80	0.36	0.15	11.0	3.10	25.1	0.36	19
5	4000	225	4.65	0.36	0.25	18.0	4.0	26.2	0.39	19
10	4000	115	7.40	0.40	0.20	14.5	2.90	38.2	0.33	15
15	4000	175	5.27	0.40	0.25	16.5	4.0	29.2	0.43	27
20	4000	185	4.81	0.41	0.20	15.5	4.15	29.4	0.43	27

TABLE—8 STRENGTH EPROPERTIS OF ETA REED TMP PAPER FROM REEL

Basis Weight g/m^2	Apparent density g/cm^3	Tensile index N.m/g MD/CD	Tear index mN m^2/g MD/CD	Brightness %	Sp. Scatt. Coeffi. m^2/kg	Opacity %
54.4	0.35	5.0/4.4	1.0/1.5	40.4	43.4	97.3
79.5	0.35	1.5/1.7	1.5/1.7	40.1	40.6	99.2
78.4	0.25	6.5/5.0	1.6/1.8	40.3	41.2	99.2
Hand sheets	0.36	5.25	1.9	41.0	42.8	98.7

Freeness of head box stock was between 90-110 ml CSF.

TABLE—9. STRENGTH PROPERTIES OF BLEACHED ALBEGIA FALCATARIA TMP AND CTMP PULPS

Pulp	Bleaching Chemical applied	Pulp Brightness	Pulp Yield	Freeness CSF	Drainage time	Apparent density	Burst index	Tensile index	Tear index	Brightness	Opacity	Sp. Scatt. Coeff.	Wet web properties IWWT	ITEA
	%	%	%	ml,	s	g/cm^3	$kPa.m^2/g$	N.m/g	mNm^2/g	%	%	m^2 kg	Nm/g	mNm/g
1. Unbleached TMP	—	—	95.8	210	4.69	0.48	0.25	15.0	2.0	44.6	99.3	50.0	0.32	6
2. Single stage hypo bleached TMP	15	57.6	95.4	150	5.35	0.56	0.40	17.5	2.05	55 2	93.6	42.9	0.31	5
3. Two stage hypo bleached TMP	10+5	62.1	95.1	155	5.40	0.52	0.35	19.2	2.50	60.1	92.3	40.8	0.38	8
4. Peroxide bleached TMP	1.3	60.0	91.7	225	4.80	0.46	0.20	15.0	1.90	57.7	96.0	49.8	0.32	7
5. Unbleached CTMP	—	—	92.3	240	5.20	0.67	1.65	36.5	4.35	42.2	98.0	38.9	0.67	12
6. Single stage hypo bleached CTMP	9.0	59.6	90.4	185	5.90	0.71	2.75	50.0	4.65	54.6	88.9	33.6	0.74	20
7. Two stage hypo bleached CTMP	6+3	61.8	89.7	230	5.10	0.68	2.10	45.5	4.70	57.2	88.5	35.1	0.63	17
8. Peroxide bleached CTMP	1.5	59.2	90.3	210	5.8	0.68	1.95	39.0	4.45	52.8	94.6	40.6	1.03	22

is on lower side compared to operating consistencies of commercial TMP units. Separate study was under taken on the effect of the consistency during post refining of TMP pulps. Strength development with varying consistencies were studied. The results are given in Table-7.

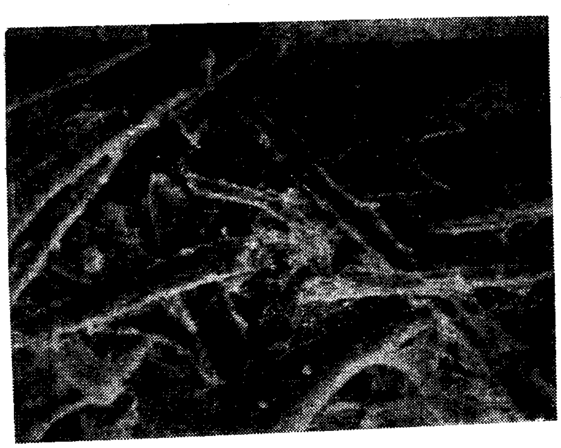
Results show that at 10% consistency, the strength development was not significant. At 5% consistency though tensile and tear were good the wet web properties were on lower side. At low consistency freeness reduction was less indicating requirement of high energy in terms of PFI revolution. Consistencies more than 15% produced pulps with higher wet web and sheet strengths. Thus for our type of raw materials it appears that consistencies between 15-20% would be optimum.

Machine runnability of eta reed TMP pulp

Large scale eta reed TMP trial produced pulp of lower strength due to extensive fibre cutting by pulp clogged plates, Inspite of low wet web strength satisfactory runnability was observed on the machine. With 100% TMP alone the lowest grammage of $54 g/m^2$ at the machine speed of 120 ft/min, was obtained. The strengths of machine made paper sample are given in Table-8

Observation of machine made paper samples through scanning electron microscope (SEM-photomicrographs 8 and 9) showed that fibers were damaged severely. The fibrillation was poor.

More study will have to be carried out to achieve better fibrillation of these fibres with suitable plate pattern.



8. SEM. Photomicrograph Etareed TMP. Sheet

9. SEM Etareed TMP fibre showing damage

Bleaching of pulps

Kenaf and eta reed thermomechanical pulps showed poor bleaching response towards both hypochlorite and peroxide. For eta reed TMP, after addition of 20% hypochlorite, brightness increased only by four units (42 to 46%). For kenaf TMP pulp inspite of its high initial brightness (49.4%) only two units of brightness development with 7.5% hypochlorite was obtained at the yield loss of 8.5%. For these pulps alternative bleaching chemicals and processess like refiner bleaching have to be studied.

A. falcataria TMP and CTMP were easily bleached to 60% brightness both by hypochlorite and peroxide. Bleaching data, and strength properties of bleached pulps are given in Table-9.

Two stage hypo chlorite bleached TMP showed better strength properties. Peroxide bleached pulps had higher scattering coefficients. The hypochlorite bleached CTMP showed tensile index as high as 50.0 N.m/g. It shows that bleaching helped in further development of strength properties.

Colcusions :

1. Thermomechanical pulps of satisfactory strength properties could be produced both from eta reed and *A. falcataria*, kenaf produced TMP with lower strength properties.
2. Preheating temperature is an important process variable. For eta reed 120°C was the optimum temperature. For different raw materials optimization of preheater temperature would be necessary.

3. Plate pattern is an important machine variable which has influence on the strength development of the pulps. Pattern with fine perfect refining zone gave TMP of improved strength. More studies would be required to select suitable plate pattern for indigenous raw materials which will allow free flow of pulp, less energy input and efficient refining.
4. High consistency refining (more than 15%) showed improved wet web properties of pulps and required less energy.
5. Eta reed thermomechanical pulp showed satisfactory runnability on machine. Paper produced had good brightness and formation.
6. *A. falcataria* TMP and CTMP pulps showed good bleaching response, while eta reed and kenaf showed poor response.
7. Studies indicate that with thorough knowledge of the optimum process variables it would be possible to produce TMP and CTMP pulps, of improved quality from indigenous raw materials, which can replace chemical grade pulp in newsprint manufacture.

Experimental

Raw material : Eta reed (*Ochlandra travancorica*) and *Albegia falcataria* were supplied by Kerala Newsprint Project. It has been established by silviculturist that *A. falcataria* is a species par excellence as far as field performance is concerned. It is a fast growing low density wood. Kenaf was supplied by M/s. Andhra Pradesh Mills Ltd. The raw material data is given in Table-1.

TMP Pilot Plant equipment : The detailed lay out of pilot plant is given elsewhere[4]. Chips from metering bin were charged to rotary valve through a twin screw conveyer. Then the chips will be taken into preheater installed on pressurized refiner (ROP-20). Chips are retained in the preheater at desired temperature and dwell time. The volume of the chips in preheater is maintained constant throughout. Chips from preheater are then fed to grinding discs of pressurized refiner through screw conveyer. The pulp from primary refiner is blown into cyclone from where it is charged to secondary open discharge refiner (RO-20) through screw conveyer. Both the refiners are powered by 200 KW motors. The pulp from secondary refiner is collected in the chest at the bottom of the unit.

Preparation of the pulps : The chips were washed to remove the grit and other foreign materials. Washed chips were soaked in water for over night for moisture saturation which is important for lignin softening during dwell time. For CTMP the chips were soaked for overnight in 12g/l solution of NaOH and Na_2CO_3 (70 : 30 ratio as NaOH). Next day the water and liquors were drained and chips were ready for pulping. The moisture untake by the chips is given in Table-1. For different raw materials for primary refining the plate pattern 5821 was used. In case of secondary refiner finer plate pattern 5811 was used. The refining conditions for different raw materials is given in Table-2. For batch trials 20 kg of OD chips was used. For large scale trial of eta reed 300 kg chips was used.

Fiberizing and spent liquors from TMP and CTMP pulping were analysed for various pollutional parameters. The yield loss during thermomechanical pulping was calculated from the amounts of organic material dissolved.

Post refining of the pulps

Where the freeness value of TMP pulps was more than 300 ml. (CSF) further beating of these pulps was carried out in PFI mill. Hand sheets of 60 g/m^2 were prepared after latency removal at 2.0% consistency, for half an hour at 80°C. During sheet making the back water was recycled to ensure that fines are not lost.

Pulp testing

The testing of wet web properties and sheet strength properties were carried out as per ISO and SCAN standards given in the manual of laboratory research methods[5].

Bleaching of the pulps : TMP and CTMP pulps were bleached separately by hypochlorite and peroxide. Hypochlorite bleaching was carried out both by single stage and two stage. Following conditions were used during bleaching.

Bleaching chemical	consistency, %	Temp. °C	Time min.
Hypochlorite	8	40	120
Peroxide	8	60	60

For peroxide bleaching EDTA, magnesium sulfate and sodium silicate, were added as inhibitors and buffers.

Pilot Plant scale paper making

About 260 kg thermomechanical pulp from eta reed was produced The latency was removed in hydrapulper at 2.6% consistency for one hour at 80°C. After latency removal the pulp was given brushing action in conical refiner before taken to head box. Different samples from the reel were collected for testing of strength properties.

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