Suitability of Andaman Hardwoods for Papermaking-1

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SUMMARY

Optimisation of pulping experiments was carried out on Andaman hardwoods using the novel method of Plackett-Burman statistical experimental design. The effect of important process variables like active alkali, top temperature, time at top temperature and black liquor addition on pulp and black liquor characteristics was studied. The extent of influence of each process variable on the above properties is evaluated. Large scale pulping experiments were carried out under optimum conditions and the pulp was bleached by CEHH sequence to a brightness of 77% ISO. The pulping results indicate that Andaman hardwoods can be used for making papers of good quality.

The ever-increasing demand for paper and shortage of conventional raw materials necessitated the industry to search for alternative raw materials. As the tropical hardwoods constitute a major resource to be tapped for this industry, existing mills are drawing the woods from these forests for making up the shortages in raw material. The dwindling supply of bamboo has compelled the mills to use the hardwood fibre to the extent of 30 to 50% in the furnish along with bamboo and softwoods. Further expansion schemes and new ventures for producing paper are to be based entirely on the tropical hardwoods. One of the unexploited tropical forests with abundent resource of hardwoods is in Andaman island. There have been various considerations in the recent past to start new ventures for production of paper using the raw materials from Andaman. Therefore, investigations were carried out on a composite sample of woods collected from Parnashala area located in middle Andaman island. The results of these investigations carried out using the novel method of Plackett-Burman design are presented in this paper.

Sampling : Random sampling plan was applied and the samples of 12 non-commercial species were collected in the form of discs after classifying the existing non-commercial species in the two dia. classes of 10-40 cms and 41-100 cms. Further, the lops and tops of two commercial species were also mixed as they would be available for the pulp wood. The discs samples received at the project site were already treated with 1% sodium pentachlorophenate solution to prevent fungus infection. Chipping was carried out after slicing them into suitable sizes. The composite sample was prepared mixing the chips in proportion of their occurrence in the forest as given in Table 1.

TABLE—1 COMPOSITION OF ANDAMAN MIXED HARDWOODS OF SAMPLE PLOT I PARNASHALA*

Sl. No.	Name of the species	Percentage contribution in each girth class: 30 cms— 120 cms % w/v	121 cms— 300 cms % w/v
1.	Actephila excelsa	2.80	—
2.	Cerolia brachiata	2.15	—
3.	Eleocarpus spp.	0.14	11.42
4.	Euginea spp.	7.97	8.72
5.	Glycosmis pentaphylla	6.43	1.04
6.	Mesua ferrea	3.46	—
7.	Memycylon coerulleum	1.47	—
8.	Myristica spp.	5.25	4.13
9.	Oroxylum indicum	1.05	—
10.	Polyalthia spp.	4.72	—
11.	Sideroxylon ferruginium	8.55	—
12.	Xanthophylium andamanicum	5.86	1.32
	Commercial species		
13.	Dipterocarpus spp.	10.83	
14.	Endospermum chinense	2.69	

Basic density of composite sample = 571 kg/m^3

*Taken from Forest inventory data

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EXPERIMENTAL :

Pulping : Pulping experiments were carried out in series digester consisting of six bombs each of 2.5 litres capacity, rotating in electrically heated polyethylene glycol bath. In each bomb 400 gm A. D. chips were taken. Pulping and washing was carried out as described in the laboratory manual[1]. In assessing the suitability on the raw material, pulping experiments were carried out according to Plackett-Burman design[3]. The general experimental design of Plackett Burman is given in Table 2, wherein it can be observed that the second line onwards subsequent lines are generated by cyclic rotation one space to the left. The last line contains all variables at low levels. The experimental design of the present investigation is given in Table 3. Large scale pulping was carried out under optimum conditions and the resultant pulp was bleached by CEHH sequence[1].

In order to assess the suitability of the raw material, the influence of the following process variables on the quality of the pulp were studied: –

i) Top temperature
ii) Time at top temperature
iii) Active alkali
iv) Black liquor addition.

The extreme levels taken for the above variables were as given below:—

		Low level	High level
i)	Top temperature	165°	175°C
ii)	Time at top tempereture	90 min.	180 min.
iii)	Active alkali	16%	20%
iv)	Black liquor addition	0	20%

TABLE—2 VARIABLE PLACKETT-BURMAN DESIGN FOR COOKING CONDITIONS

Cook No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7
1.	+	+	+	—	+	—	—
2.	+	+	—	+	—	—	+
3.	+	—	+	—	—	+	+
4.	—	+	—	—	+	+	+
5.	+	—	—	+	+	+	—
6.	—	—	+	+	+	—	+
7.	—	+	+	+	—	+	—
8.	—	—	—	—	—	—	—

TABLE—3 THE EXPERIMENTAL PLAN ACCORDING TO PLACKETT BURMAN USED IN COOKING EXPERIMENTS OF ANDAMAN HARDWOODS

Cook No.	A	B	C	D	E	F	G
1.	175	180	20	0	+	—	B
2.	175	180	16	20	—	—	A
3.	175	90	20	0	—	+	A
4.	165	180	16	0	+	+	A
5.	175	90	16	20	+	+	B
6.	165	90	20	20	+	—	A
7.	165	180	20	20	—	+	B
8.	165	90	16	0	—	—	B

Constant Conditions :

Liqour to wood ratio—3 : 1
Sulphidity —25%
time to top temperature – 105 min.

A = top temperature
B = time at top temperature
C = active alkali
D = black liquor addition
E = Dummy
F = Dummy
G= Laboratory factor
(A : High level)

The percentage of black liquor addition was based on total liquor (including chip moisture) and the active alkali percentage shown includes the residual alkali contribution from the black liquor addition. The high and low levels were chosen so that they are not so remote from the normal cooking conditions as to produce drastically abnormal yields, Kappa numbers and H factors. The assumption made is that within the restricted range of each variable, the response is essentially linear, The relative effects of the above four pulping process variables on pulp characteristics studied using Plackett-Burman design.

RESULTS AND DISCUSSIONS

Pulp and black liquor charscteristics from the eight cooks are presented in Table 4. Table 5 shows the main effects of process variables on each pulping characteristic and their relative ranking. The sign of the effect indicates in which direction the response moves when the variable changes from its low to high level. The main effect of -2.5 for the influence of top temperature on total pulp yield means that yield will decrease by 2.5% when top temperature is changed from 165°C to 175°C irrespective of changes associated with the other variables. Table 6 gives more

TABLE—4 PULPING DATA

Cook No.	H factor	Total pulp yield %	Screen rejects %	Kappa number	Black liquor Total solids % w/w	Black liquor R.A.A. as Na_2O at 200 g/l total solids	Viscosity (cps) at 55% total solids
1.	4545	40.5	0.8	20.1	23.9	9.13	17.4
2.	4545	44.7	1.6	30.9	24.0	5.80	31.2
3.	2470	41.5	0.9	21.5	24.3	8.40	12.6
4.	2025	46.4	1.1	26.8	19 8	8.10	63.0
5.	2470	48.3	4.2	31.9	26.9	6.90	15.1
6.	1110	46.4	1.6	26.5	25.3	10.60	18.9
7.	2025	44.1	0.8	23.0	25.6	7.90	29.1
8.	1110	47.9	2.4	29.7	20.7	7.40	31.6
Mean	2538	45.0	1.7	26.3	23.8	8.02	27.4

TABLE—5 MAIN EFFECTS OF PROCESS VARIABLES ON PULP AND BLACK LIQUOR PROPERTIES AND RELATIVE RANKING

Variable	H factor	Total pulp yield %	Screen rejects %	Kappa No.	Black liquor Total solids % w/w	Black liquor R A.A. as Na_2O at 200 g/l total solids	Viscosity (cps) at 55% total solids
Top temperature	1939	−2.5	0.4	—0.4	+1.9	—0.97	—16.59
	(1)	(2)	(6)	(5)	(2)	(3)	(1)
Time at top temperature	1494	—2.2	−1 3	—2.2	−1 0	−0 59	+15.62
	(2)	(3)	(2)	(3)	(4)	(4)	(3)
Active alkali	0	—3 8	—1.4	—7.1	—1.89	1.98	—15.73
		(1)	(1)	(1)	(3)	(1)	(2)
Black liquor addition	0	1.8	0.7	+3.6	3.25	—0 44	— 7.56
		(4)	(4)	(2)	(1)	(6)	(5)
Dummy	0	0.8	0.5	+0.1	0.32	1.31	2 49
		(5)	(5)	(7)	(7)	(2)	(7)
Dummy	—581	0.2	0.1	—1.0	0.65	—0 45	5.20
	(3)	(7)	(7)	(4)	(6)	(5)	(6)
Laboratory factor	0	—0 5	—0.8	+0.3	—0.96	+0.40	8.11
		(6)	(3)	(6)	(5)	(7)	(4)

TABLE 6—MOST INFLUENTIAL PROCESS VARIABLES ON VARIOUS PULP AND BLACK LIQUOR PROPERTIES

Property	Process variables	Main effect as % of mean
Total pulp yield %	Active alkali	—8.4
	Top temperature	—5.6
	Time at top temperature	—4.9
	Black liquor addition	+4.0
Kappa number	Active alkali	—27.0
	Black liquor addition	+13.7
	Time at top temperature	—8.4
R.A.A. as Na_2O g/l	Active alkali	+24.7
	Top temperature	—12.1
	Time at top temperature	—7.4
	Black liquor addition	—5.5
Total solids in black liquor, % w/w	Black liquor addition	+13.7
	Top temperature	+8.0
	Active alkali	+7.9
Black liquor viscosity at 55% solids (cps)	Top temperature	—60 6
	Active alkali	—57.5
	Time at top temperature	+57.1

influential process variables and their effects on pulp and black liquor properties. The effects have been expressed as percentage of the mean value of all pulps. This table clearly shows the extent to which the individual process variables govern the pulp and black liquor properties. After knowing the significant process variables, which have considerable influence on the pulp and black liquor properties, we can arrive at the mathematical models as given in Tables 7 and 8. Using these mathematical equations, we can calculate and predict the various pulp and black liquor characteristics for any type of pulping conditions involving the above process variables, within the limits studied. Experimental values and those calculated by mathematical equations are given in Table 9. These are very close demonstrating the validity of the mathematical models.

Active alkali, top temperature and time at top temperature are significant pulping process variables in terms of pulp characteristics. An active alkali increase of 1% results in a decrease of total pulp yield by 1%, Kappa number by nearly two units. Black liquor addition upto 20%, results in an increase of Kappa number by 3.6 units, total solids by 3%, decrease of pulp brightness by 1.4%. 5°C rise in cooking temperature and 45 min. increase of cooking time at 165°C, are having similar effect

TABLE 7 PRELIMINARY MATHEMATICAL MODELS FOR DIFFERENT PROCESS VARIABLES

	Quality factor					
Top temperature	—2.5	b_1	=	$\frac{-2.5}{10°C}$	=	$\frac{-0.25}{°C}$
Time at top temperature	—2.2	b_2	=	$\frac{-2.2}{90\ min.}$	=	$\frac{-0.0244}{min.}$
Active alkali	—3.8	b_3	=	$\frac{-3.8}{4\%}$	=	$\frac{-0.95}{\%}$
Black liquor addition	+1.8	b_4	=	$\frac{+1.8}{20\%}$	=	$\frac{+0.09}{\%}$

$$\text{Total yield \%} = 45.5 - 0.25\left(\frac{T}{°C} - 170\right) - 0.0244\left(\frac{t}{min} - 135\right) - 0.95\left(\frac{c}{\%} - 18\right) + 0.09\left(\frac{B}{\%} - 10\right)$$

TABLE 8—MATHEMATICAL MODELS FOR DIFFERENT PROCESS VARIABLES

1. Kappa number $K = 26.3 - 0.0244\left(\frac{t}{min} - 135\right) - 1.775\left(\frac{C}{\%} - 18\right) + 0.18\left(\frac{B}{\%} - 10\right)$

2. **R.A.A. as Na O in black liquor at 200 g/1 total solidss** R.A.A. $g/1 = 8.02 - 0.097\left(\frac{T}{°C} - 170\right) + 0.495\left(\frac{C}{\%} - 18\right)$

3. **Total solids in black liquor**
TS Black liquor % $w/w = 23.79 + 0.19\left(\frac{T}{°C} - 170\right) - 0.011\left(\frac{t}{min} - 135\right) + 0.473\left(\frac{C}{\%} - 18\right) + 0.163\left(\frac{B}{\%} - 10\right)$

4. **Viscosity of black liquor at 55% total solids cps.**
Visc (cps) Black liquor $= 27.36 - 1.659\left(\frac{T}{°C} - 170\right) + 0.174\left(\frac{t}{min} - 135\right) - 3.933\left(\frac{C}{\%} - 18\right) - 0.378\left(\frac{B}{\%} - 10\right)$

TABLE—9 COMPARISION OF THE RESULTS CALCULATED WITH THE MATHEMATICAL MODELS WITH THOSE OBTAINED EXPERIMENTALLY

Particulars	Experi-mental	Calcu-lated	Experi-mental	Calcu-lated	Experi-mental	Calcu-lated	Experi-mental	Calcu-lated
Total pulp yield %	40.5	39.9	44.7	45.5	41.5	42.1	46.4	46.2
Screen rejects %	0.8	0.4	1.6	1.8	0.9	1.7	1.1	1.4
Kappa number	20.1	19.9	30.9	30.6	21.5	22.1	26.8	27.0
Black liquor								
a. Total solids, % w/w	23.9	23.6	24.0	24.9	24.3	24.6	19.8	19.8
b. RAA as Na_2O g/l at 200 g/l total solids	9.1	8.5	5.8	6.6	8.4	8.5	8.1	7.5
c. Viscosity cps at 55% total solids	17.4	22.8	31.2	31.0	12.6	7.1	63.0	55.1

on yield i.e. yield is reduced by 1%, wherease increase of cooking time is more effective in reducing Kappa number of the pulp.

Based on these small scale experiments, large scale experiments, large scale cooking experiment was carried out according to conditions given in Table 10. The result obtained and those calculated using mathematical models are given in Table 11. These values are very close thereby proving the validity and effectiveness of the method.

TABLE 10—LARGE SCALE PULPING OF ANDAMAN HARDWOODS

1.	Chemical as Na_2O %	16.0
2.	Sulphidity of the cooking liquor %	25.0
3.	Chips to liquor ratio	1:3
4.	**Cooking schedule**	
	Raising time to 100°C min.	30
	From 100°C to 170°C min.	105
	At 170°C min.	90
5.	H Factor	1660
6.	Total pulp yield %	48 0
7.	Screen rejects %	3.3
8.	Kappa number of the unbleached pulp	30.3
9.	**Black liquor**	
	a. pH	10.9
	b. Total solids % w/w	18.34
	c. Residual active alkali Na_2O g/l (at 200 g/l total solids)	8.04
	Inorganics as NaOH %	30.68
	Swelling volume ratio ml/g	10
	Viscosity at 80°C	
	35% w/w TS	3.6 cps
	45 ,,	9.0 ,,
	50 ,,	22.0 ,,
	55 ,,	53 ,,
	Precipitation point = 46 2% total solids.	

TABLE 11—COMPARISON OF THE RESULTS PREDICTED WITH THE MATHEMATICAL MODEL WITH THOSE OBTAINED EXPERIMENTLLY FOR LARGE SCALE PULPING

Particulars	Experimental	Calculated
Total pulp yield %	48.0	47.1
Screen rejects %	3.3	2.7
Kappa number	30.3	29.2
Black liquor		
a. Total solids % w/w	18.3	21.7
b. RAA as Na_2O at 200 g/l total solids	8.04	7.0

The pulping results show that a pulp of Kappa number around 30, can be obtained at an yield of 48%, using 16% chemicals at 170°C for 90 minutes. In comparison to Baster hardwoods pulpability is good[2]. For Baster hardwoods, pulp of Kappa number 27 is obtained with an yield of 43.4%, using 16% chemicals at 170°C for 120 minutes. Strength prop rties are better than those of other hardwood pulps including tear (11.2 mNm^2/g)

TABLE 12—STRENGTH PROPERTIES CALCULATED AT 300 ml CSF

Cook No.	Burst index kPa m^2/g	Tensile index Nm/g	Tear index mNm^2/g
1.	2.67	48.0	7.21
2.	3.80	57.5	9.60
3.	2.98	51.0	8.3
4.	3.80	60.0	10.2
5.	3.40	56.5	10.05
6.	3.80	57 5	10.2
7.	3.35	53.0	9.15
8.	4 05	56.3	10.65

From the black liquor properties given in Table 10, it can be observed that precipitation point is high (i. e. at 46.2% total solids) and viscosity at 55% total solids is quite low (53 cps).

The above pulp of Kappa number 30.3 was bleached by CEHH sequence under optimum conditions. The bleaching conditions are given in Table 14. The strength properties of both unbleached and bleached pulps are presented graphically in Figs 1 to 3.

Bleaching results show that using 8.7% Cl_2, a brightness of 77% ISO is attained. The pulp viscosity is also high (620 cm^3/g). The strength properties of bleached pulp shows that they are on par with unbleached pulp properties.

TAELE—13 EFFECT OF MOST INFLUENTIAL PROCESS VARIABLES ON VARIOUS PULP PROPERTIES ESTIMATED AT 300 ml CSF

Property	Process variable	Main effect as % of mean
Burst index	Active alkali	−16.1
	top temperature	−15.5
	Black liquor additio	+ 6.3
Tensile index	Active alkali	− 9.5
	top temperature	− 6.3
	Black liquor addition	+ 4.2
Tear index	Active alkali	−16.1
	Top temperature	−12.6
	Time at top temperature	− 7.2
	Black liquor addition	+ 6.1

TABLE—14 BLEACHING OF SAMPLE PLOT I COMPOSITE PULP BY CEHH SEQUENCE

Sl No.	Particulars		
	Kappa number of the pulp		30.3
1.	**Chlorination**		
	Chlorine added on pulp	%	6.8
	initial pH		1.8
	final pH		1.9
	Chlorine consumed on pulp,	%	6.74
2.	**Alkali extraction**		
	Alkali applied as sodium hydroxide,	%	2.0
	initial pH		10.8
	final pH		10.5
3.	**Hypo I stage**		
	Hypochlorite applied as chlorine,	%	1.4
	Buffer added as sodium hydroxide to maintain pH>9 0	%	0.36
	Hypochlorite consumed as chlorine,	%	1.25
4.	**Hypo II stage**		
	Hypochlorite applied as chlorine,	%	0.5
	Buffer added as sodium hydroxide to maintain pH> 9.0	%	0.1
	Hypochlorite consumed as chlorine,	%	0.2
5.	Yield loss during bleaching,	%	5.7
6.	Total chlorine applied,	%	8.7
7.	Total chlorine consumed,	%	8.2
8.	Total sodium hydroxide used,	%	2.46
9.	Brightness of the pulp,	% ISO	77.0
10.	Intrinsic viscosity of the pulp, cm^3/g		620

Constant conditions :

		Chlorination	Alkali extraction	Hypo I stage	Hypo II stage
Consistency, %	=	3	8	8	8
Temperature, °C	=	30	60	40	40
Time, min.	=	30	60	120	120

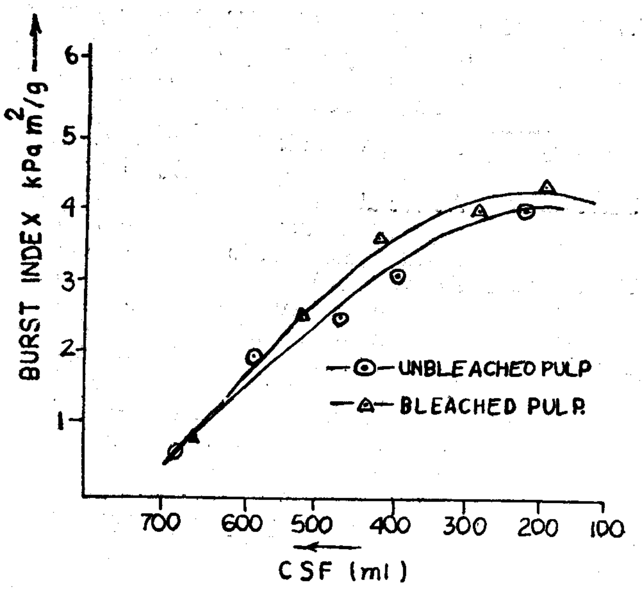

Fig 1

Burst Index V/s CSF for Andaman Hardwoods Sample Plot I Unbleached and Bleached Pulps

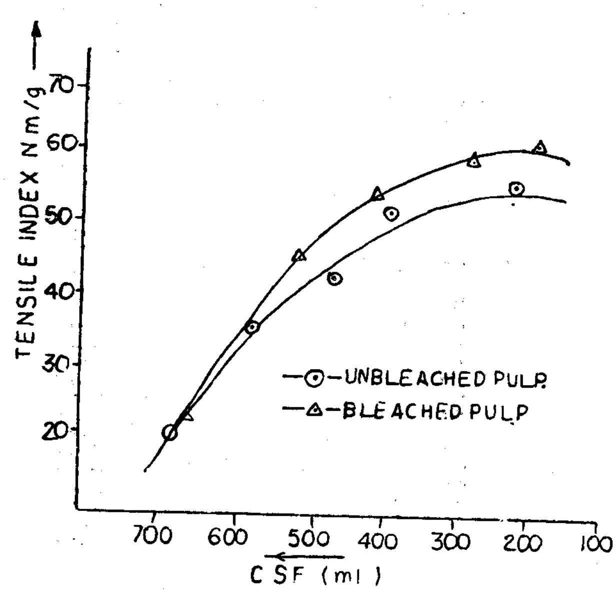

Fig. 2

Tensile Index V/s CSF for Andaman Hardwoods Sample Plot I Unbleached and Bleached Pulps

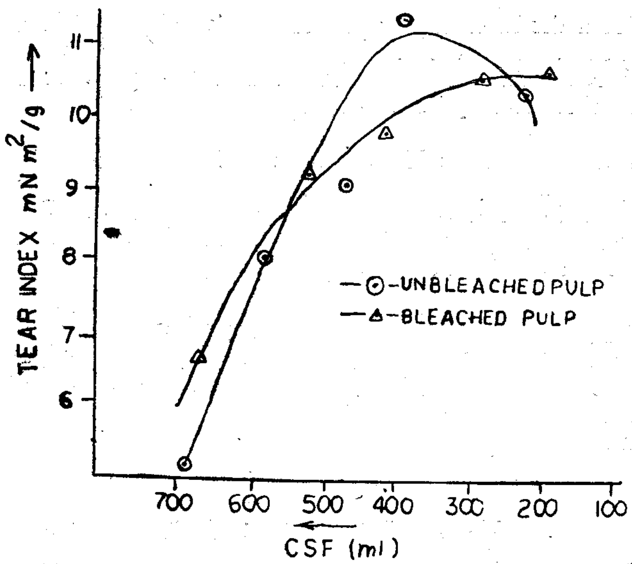

Fig. 3

Tear Index V/s CSF for Andaman Hardwoods Sample Plot I Unbleached and Bleached Pulps

CONCLUSIONS

1. Plackett-Burman experimental design can be effectively used in optimising the cooking conditions in attaining the desired pulp and black liquor characteristics within the limits of the variables studied.
2. Using 16% chemical at 170°C for 90 minutes, it is possible to obtain bleachable grade pulp from Andaman hardwoods.
3. Black liquor characteristics like precipitation, viscosity are better than those of hardwoods.
4. Bleaching response of the pulp is quite good. With 8.7% Cl_2 a pulp of 77% ISO brightness can be obtained.
5. The strength properties of both unbleached and bleached pulps (including tear) are better than those of other hardwood pulps.

ACKNOWLELGEMENT

The authors acknowledge the assistance rendered by Mr. D. G. Suryavanshi, Mr. K S. Murthy, Mr. Y.V. Sood and Mr. T.K. Roy.

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