

# Studies on alkali-peroxide delignification of *Cannabis sativa*—A non sulphur process.

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## ABSTRACT

The alkali-peroxide (AP) and peroxide-alkali (PA) processes use no sulphur and give results comparable to that of the kraft process. The main advantage of this process is the elimination of odorous pollutants. During AP process, the delignification is performed in two stages. In the first stage, cooking with 13% active alkali with 0.1% AQ reduces the Kappa number around 50. In the second stage, the treatment with 3% H<sub>2</sub>O<sub>2</sub> and 3% alkali does lower the Kappa number to around 30. Refining of pulp in two stages improves the results further. The PA process is operated only in single step.

During PA process the treatment was given with, 16% alkali, 3% H<sub>2</sub>O<sub>2</sub> and 0.1% AQ dose. The resulting pulp yield is 2-5% higher than the corresponding yield for kraft, and the pulp was much more brighter. On the basis of experimental results, it can be concluded that both the pulp yield and strength properties were found slightly higher in PA process than the AP process. The unbleached pulp was bleached by using CEDPD bleaching sequence, produced pulps with a brightness level of 82% (Elrepho). The alkaline peroxide delignification process are desirable alternatives to the kraft process. It also completely solves the problems of air pollution caused by sulphur components of kraft process.

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## Introduction :

The kraft delignification is today's most important chemical pulping process. Its success has been founded on the excellent quality of the kraft pulp and the flexibility of the process itself. Its main draw back i.e. poor bleachability, has been overcome by the use of chlorine dioxide as a bleaching agent. However not only lignin but also all carbohydrates are attacked by the cooking liquor, the alkaline pulping destroys about 20% of the original amount of cellulose. This results in rather poor efficiency when compared with that of other pulping methods.

The addition of sodium sulphide has been beneficial particularly for the pulping of coniferous species, leading to lower lignin content for a given yield. The loss of sulphur during evaporation of the black liquor and combustion of the residue is undesirable, however when compared from the standpoints of both economics and air pollution control. Sulphur escapes as hydrogen sulphide, dimethyl sulphide and methyl mercaptans which are very odorous gases, even in extremely small amounts. The various methods

developed to eliminate, these gases such as black liquor oxidation and scrubbing of stack gases are expensive and cannot eliminate them completely. A few parts per million still remain and unfortunately, the human olfactory sense can detect the smell of a few parts per billion. Air pollution from kraft mills is thus a serious problem and has recently attracted considerable public attention, and is under investigation by the environmental protection agency.

The recent discovery (1) of the catalytic effect of anthraquinone (AQ) related derivatives in the alkaline cooking has raised interest in sulphur free pulping process. Unfortunately numerous studies (2-6) soon revealed that the process though simple and efficient had certain draw backs, such as lower pulp strength, (of major concern in soft wood pulps) inferior pulp bleachability and higher production cost because of

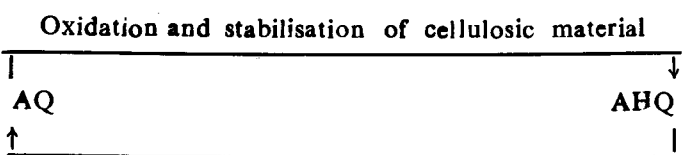
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the significant amount of AQ consumed. The draw back can be traced to the excess amount of AQ used in order to get a bleachable grade pulp and to the degradation of cellulose at the end of the cook. During delignification, the carbohydrates (reducing substances) reduces anthraquinone to Anthrahydroquinone and ultimately to its soluble an ionic form with dark red colour.

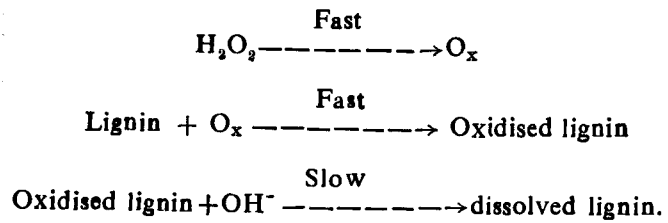
Anthrahydroquinone, inturn reduces lignin fragments dissolved in the liquor and is oxidised back to anthraquinone, than closing the catalytic cycle of its dual function as pulping aid.



Reduction of dissolved lignin which prevents recondensation.

In order to reach a still lower kappa number an additional delignification agent has to be found. Hydrogen peroxide in alkaline medium achieves this goal advantageously.

The delignification process with H<sub>2</sub>O<sub>2</sub> is most likely the result of the following reactions.



The first step of delignification seems to be fast oxidation of the lignin by the O<sub>x</sub> components (OH<sup>-</sup>, O<sub>2</sub><sup>-</sup>, O<sub>3</sub>). The second step would be a slow dissolution of the oxidised lignin in alkaline medium. This explains the fast disappearance of the hydrogen peroxide and accounts for the lack of effect displayed by the sodium silicate, other researchers have found that in certain case a pulp quality was improved by the addition of magnesium sulphate (7). The latter decreases the depolymerisation of the cellulose.

The non sulphur pulping process not only eliminates the production of these pollutants but also increases the pulping efficiency by 2 to 5% based on the

weight of the wood. The idea is to combine the catalytic effect of anthraquinone and its derivatives and the delignification capability of hydrogen peroxide into one single process. The same basic equipment as used in kraft pulp mill can be utilised (thus the obvious possibility of easy conversion to new method in existing plants).

**Experimental Methodology :**

**Raw Material And Its Preparation :**

The stalks of C. sativa were collected from nearby regions of Saharanpur and chopped by hand to chips of approximately 20 mm in length. It was then screened and chips those passing through 30 mm screen but retained on a 20 mm screen were collected. The accepted chips were air dried under atmospheric condition.

**Proximate Chemical Analysis :**

Screened air dried chips were disintegrated in the laboratory WEVERK disintegrator. The portion passing through 40 mesh sieve but retained on 80 mesh sieves was utilised for proximate chemical analysis. The proximate chemical analysis was carried out as per standard TAPPI procedures. The results are reported in Table-1.

**Maceration And Cellular Elements Measurement :**

Transverse and longitudinal sections of 20 to 30 μ thickness of C. sativa plants were cut on lietz base sludge microtome 1300 For morphological studies, the samples were subjected to a chemical physical maceration to separate the individual cellular elements from each other without damage. It involved the use of a hot aqueous acetic acid and sodium chlorite solution to remove most of the lignin and other binding materials without appreciable degradation of the cellulosic tissues. The microscopic slides of cellular material prepared according to IS method 5285-1969. Microscopic slides were projected at a magnification of 40 X and the fibre length were measured. Fibre width and cell wall thickness were obtained by measuring the projected images at a magnification of 160 X. The values of density, fibre length, fibre diameter lumen diameter, cell well thickness and different ratios of the above dimensions are reported in Table-2.

**TABLE-1**  
Proximate Chemical Analysis of *Cannabis sativa*, Bagasse, Bamboo and *S. aculeata*.

Sl. No.	( Particulars )		C sativa	Bagasse (10)	Bamboo (9)	S. aculeata (8)
1	Cold water solubles,	%	3.94	5.91	7.60	2.64
2	Hot water solubles,	%	7.46	7.85	8.50	3.32
3	Alcohol benzene solubles, (1:2 V/V)	%	3.50	6.30	3.40	3.28
4	1% NaOH solubles,	%	24.00	33.60	26.80	22.40
5	Lignin,	%	18.25	20.30	24.30	19.79
6	Pentosan,	%	16.40	23.85	18.30	17.56
7	Holocellulose,	%	73.80	70.60	71.50	78.85
8	Hemicellulose,	%	24.40	28.45	27.60	26.40
9	Alphacellulose,	%	49.40	42.00	43.50	48.00
10	Betacellulose,	%	10.60	—	13.40	12.75
11	Gammacellulose,	%	13.50	—	14.00	13.40
12	Ash,	%	1.30	3.80	2.10	1.78
13	Silica,	%	0.25	2.10	1.40	0.50
14	Acetyl content,	%	3.12	—	2.50	2.40
15	Methoxyl Content,	%	3.56	—	3.10	4.17

**TABLE-2**  
Morphological Characteristics of *Cannabis sativa*.

Sl No.	Particulars	C. sativa
1	Density gm/cm <sup>3</sup>	0.326
2	Fibre length, (L) mm	
	Average	1.775
	Variation	0.396-5.55
3	Fibre width, (D) ( $\mu$ )	
	Average	29.536
	Variation	11.36-39.40
4	Lumen Width, (d) ( $\mu$ )	
	Average	15.21
	Variation	11.080-18.816
5	Cell wall thickness, (W)	
	Average	7.056
	Variation	2.176-11.776
6	Flexibility Coefficient, (d/D x 100)	51.50
7	Ratio of length to width, (L/D)	60.096
8	Ratio of twice cell wall thickness to fibre width, (2W/D)	0.478
9	Wall fraction, (2W/dx100)	92.76
10	Runkel ratio, (2W/d)	0.9276
11	Ratio of cell wall thickness to lumen width, (W/d)	0.4638

### Pulping Studies :

The *C. sativa* chips were digested in electrically heated WEVERK rotary digester of 0.02 m<sup>3</sup> capacity, having 4 bombs of one liter capacity, furnishing sufficient pulp for evaluation as well as for bleaching experiments. During the course of pulping, the liquor to wood ratio of 3.5:1 was maintained and the following cooking schedule for digester heating was adopted.

Time from room temp. to 105°C	= 45 minutes
Time from 105°C to 165°C	= 45 minutes
Time at 165°C	= 180 minutes

On completion of cooking cycle, the digester pressure was reduced by gas relief until the temperature lowered to 105°C. The charge was then blown from the digester. The pulp was washed on a laboratory flat stationary screen having 300 mesh wire bottom for the removal of spent liquor. The pulp was further disintegrated in the laboratory disintegrator. The disintegrated pulp was further screened through a vibratory flat screen and the screened pulp was further evaluated.

The digestion of *C. sativa* chips was done by alkali-peroxide AQ (two stage) and peroxide-alkali-AQ (single stage) pulping methods and compared with soda, soda-AQ, kraft and kraft-AQ delignification process.

### Soda And Soda-AQ Pulping

The soda and soda-AQ pulping studies of *C. sativa*, chips were done at following conditions :

Active alkali dose (as Na <sub>2</sub> O), (%)	= 16
Time to temperature (Minutes)	= 90
Time at temperature (Minutes)	= 180
Maximum temperature, (°C)	= 165
Liquor to wood ratio	= 3.5:1
AQ dose (o d. wood basis), (%)	= 0.0, 0.05, 0.1 and 0.2

The results of soda and soda-AQ pulping of *C. sativa* are reported in table-III and illustrated in figure-1.

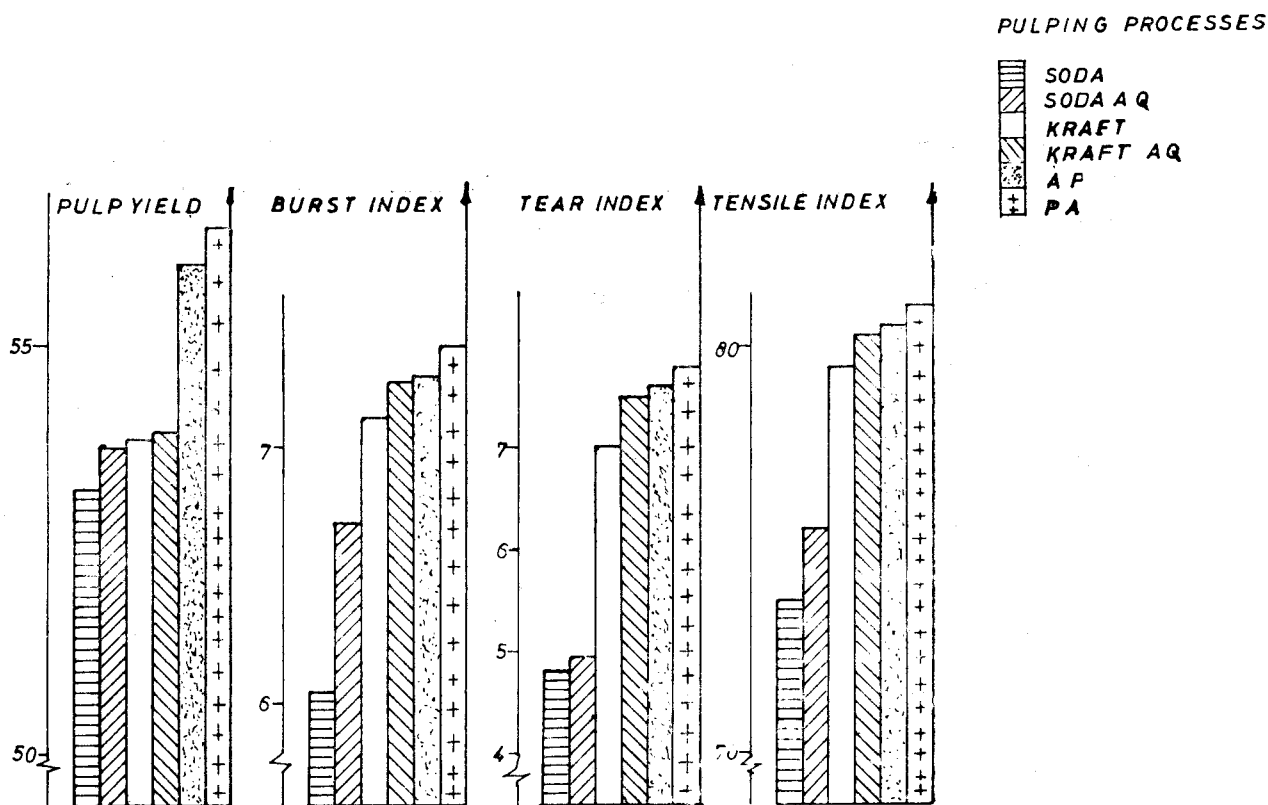


FIG.1 :- COMPARISON OF PULP YIELD AND PHYSICAL CHARACTERISTICS OF SODA AND SODA-AQ KRAFT AND KRAFT-AQ AP AND PA PULPING PROCESSES AT OPTIMUM CONDITION OF *C. sativa*

## Kraft and Kraft-AQ Pulping

The kraft and kraft-AQ pulping studies of *C. sativa* chips were done at following conditions.

Active alkali dose (as Na <sub>2</sub> O), (%)	= 16
Sulphidity, (%)	= 20
Time to temperature (minutes)	= 90
Time at maximum cooking temperature, (minutes)	= 120
Maximum temperature (°C)	= 165°C
Liquor to wood ratio	= 3.5:1
AQ dose (o.d. wood basis), (%)	= 0.0, 0.05, 0.1 and 0.2

The results of kraft and kraft-AQ pulping of *I. carnea* are reported in table-IV and illustrated in figure-1.

## Alcaper Process (Alkali-Peroxide or AP, Process)

The *C. sativa* chips were digested by Alcaper process, which is a combination of the two stages (partially alkali delignified chips were further treated with hydrogen peroxide in alkaline medium. In the first stage the chips were digested with 13% alkali (as Na<sub>2</sub>O) at 165°C for 3 hours using different doses of AQ (0, 0.05, 0.1 and 0.2% on o.d. wood basis). At the end of the cooking, the Kappa number was found to be around 40. Since the Kappa number is relatively high, mechanical defibration is almost essentially required and done in a standard disk refiner,

In the second stage, the hydrogen peroxide treatment of pulp was performed in alkaline medium at atmospheric pressure at a temperature of 90°C for 90 minutes at a high pulp consistency level (around 20%). The amount of hydrogen peroxide used was 3% (based on o.d. wood basis) in presence of magnesium sulphate (1.0%). As a result of which, the Kappa number of pulp was found to be as low as 25. The result of Alcaper pulping are reported in Table-V and illustrated in figure-2.

## Peroxide-Alkali (PA Process) Process

The PA process is suitable for pulping of both woody and non-woody cellulosic materials. The energy and chemicals can be recovered from PA spent liquor

like kraft spent liquors. In order to know the optimum dose of alkali, *C. sativa* chips were digested with varying doses of alkali (14, 16 and 18% as Na<sub>2</sub>O) using 3% H<sub>2</sub>O<sub>2</sub>, 0.1% AQ and 1% magnesium sulphate. The results are reported in table-VI and figure-3.

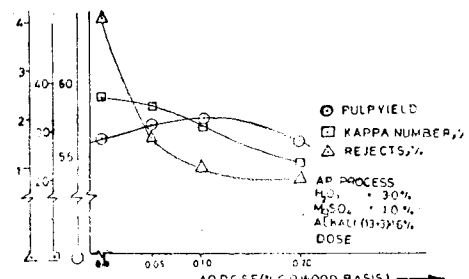


FIG. 2:- EFFECT OF AQ CHARGE ON PULP YIELD, KAPPA NUMBER, AND REJECTS OF UNBLEACHED ALCAPER PULPS

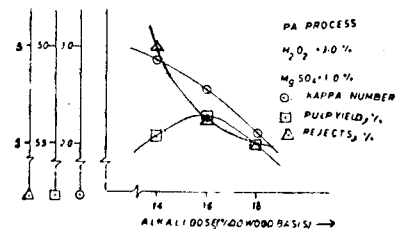


FIG. 3:- EFFECT OF ALKALI ON KAPPA NUMBER AND PULP YIELD OF UNBLEACHED PA PULPS

The *C. sativa* chips were also digested with 16% alkali (as Na<sub>2</sub>O) alongwith 3% H<sub>2</sub>O<sub>2</sub> and 1% magnesium sulphate at varying doses of AQ (0.0, 0.05, 0.1 and 0.2% on o.d. wood basis) and the results are reported in table-7 and figure. 4.

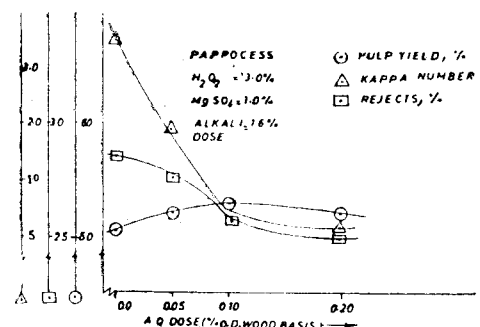


FIG. 4:- EFFECT OF AQ ON PULP YIELD, KAPPA NUMBER AND REJECTS OF UNBLEACHED PA PULPS

Further the *C. sativa* chips were also digested with 16% alkali (as Na<sub>2</sub>O) alongwith 0.1% AQ, 1% magnesium sulphate at varying doses of hydrogen peroxide

(1,2,3 and 4% based on o.d. wood basis) and the result are reported in table-8 and figure-5

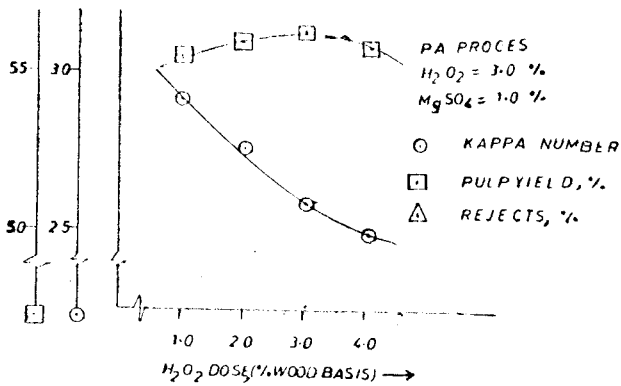


FIG 5 :- EFFECT OF H<sub>2</sub>O<sub>2</sub> ON KAPPA NUMBER AND PULP YIELD OF UNBLEACHED PA PULPS

**Bleaching Studies :**

The PA unbleached pulps were found to be more brighter (31% Elrepho) than the kraft pulp of the same Kappa number (27% Elrepho). The PA unbleached pulps have been subsequently bleached through a CEDPD bleaching sequence. The results of bleaching studies are tabulated in table-9.

**Pulp Evaluation :**

All these pulps were beaten in PFI mill with a beating pressure of 1.8 kg./cm. to different freeness levels and hand sheets of 60 gsm were prepared on standard British sheet forming machine. The hand sheets were evaluated as per BIS method for their different physical strength properties. The results of unbleached and bleached AP and PA pulps are reported in table-10 to 11 and illustrated in figures-6-9.

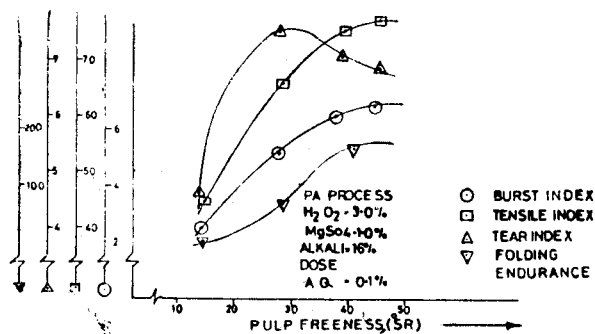


FIG. 6 :- EFFECT OF FREENESS ON STRENGTH PROPERTIES OF UNBLEACHED PA PULPS.

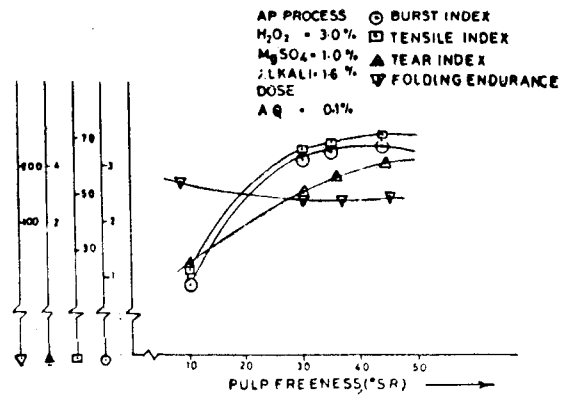


FIG. 7 :- EFFECT OF FREENESS ON STRENGTH PROPERTIES OF UNBLEACHED AP PULPS.

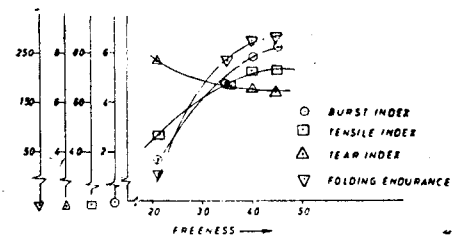


FIG 8 :- PLOTS OF FREENESS VS STRENGTH PROPERTIES OF PA BLEACHED PULPS

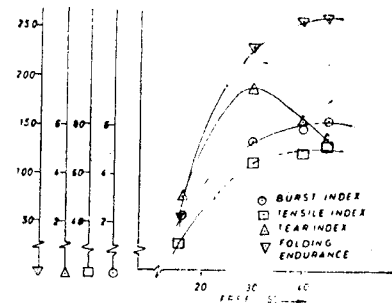


FIG 9 :- PLOTS OF FREENESS VS STRENGTH PROPERTIES OF BLEACHED AP PULPS

**Results And Discussions :**

The result of proximate chemical analysis (Table-1) indicated that the water solubles in C. sativa are 7.46% as compared to 7.85%, 8.50% and 3.32% in bagasse, bamboo and S. aculeata respectively : which is towards lower side. The alcohol-benzene solubles in C. sativa are 3.5% as compared to 6.30%, 3.40% and 3.28 in bagasse, bamboo and S. aculeata respectively. All soluble materials comes under the category of extractives and these are totally undesirable

for pulp and paper making. The solubles materials goes with spent liquor and reduce pulp yield. The 1% sodium hydroxide solubles in *C. sativa* plant are 24.00% as compared to 33.60%, 26.80% and 22.40% in bagasse bamboo and *S. aculeata* respectively, which is quite comparable with bamboo and *S. aculeata*. The lignin in *C. sativa* was 18.25% as compared to 20.30%, 24.30% and 19.79% in bagasse, bamboo and *S. aculeata* respectively. As indicated that *C. sativa* is having low lignin content thereby requiring less cooking chemicals and shorter cooking cycle. *C. sativa* is having 73.80% holocellulose as compared to 70.60% and 71.50% in bagasse and bamboo respectively. The alpha cellulose content in *C. sativa* is 49.80% as compared to 42.00% and 43.50% in bagasse and bamboo respectively.

The hemicellulose contents in *C. sativa* is 24.40% as compared to 28.48% in bagasse, 24.60% in bamboo and 26.40% in *S. aculeata*. The pentosan content in *C. sativa* is 16.40% as compared to 23.85%, 18.30% and 17.56% in bagasse, bamboo and *S. aculeata* respectively. As the *C. sativa* is having low pentosan content, therefore, it will give better pulp yield. The ash and silica contents in *C. sativa* is 1.30% and 0.25% as compared to 3.80% and 2.10% in bagasse, 2.1% and 14% as in bamboo and 1.78% and 0.50% in *S. aculeata*. As the *C. sativa* is having quite low ash and silica content so it will show less damaging effect on processability of the wood and will create less trouble during chemical recovery.

In *C. sativa* phloem fibres are fully developed. The wood fibres are tapering at both the end, while bast fibres are slightly tapering at both the end. Most of these fibres showed variable thickening & transverse factures. Cell wall cavity is narrow and nearly empty with little amount of sap. The fibre cells are many time in length as compared to width. The parenchymatous cells are also found and attached with fibre cells; and between two fibre cells pits are also found. Typical average fibre dimensions are length (by number) 1.77mm, width, 29.53  $\mu$ , lumen width, 15.21  $\mu$  and cell wall thickness 71.05  $\mu$ .

The impregnation of *C. sativa*, chips by alkali-peroxide process is carried out very easily at 165°C temperature. The charge could be fiberised into pulp without much of mechanical processing and produced pulp in high yield range with higher unbleached brightness (31% Elrepho).

Table-3 and 4 indicated the data of soda and kraft pulping of *C. sativa* alongwith the effect of AQ. As a result of addition of 0.1% AQ curing soda and kraft pulping both, the Kappa number reduced drastically alongwith a minor gain in pulp yield. The substantial reduction in Kappa number of unbleached pulp is a major gain of addition of 0.1% AQ, thereby requiring lesser bleach demand for producing bleached pulps.

TABLE-3  
Pulping results and physical strength properties of soda and soda-AQ pulps at optimum condition.

Sl. No.	Particulars	Process	
		Soda	Soda-AQ
1	Active alkali, (as Na <sub>2</sub> O) (%)	16	16
2	Rejects, (%)	1.00	0.22
3	Screened Yield, (%)	49.50	50.55
4	Unscreened Yield, (%)	50.50	50.77
5	Kappa number	33	29
6	AQ dose (%)	—	0.1
7	Burst index, (K, Pa m <sup>3</sup> /g)	6.05	5.70
8	Tensile index, (Nm/g)	73.40	75.55
9	Tear index, (m Nm <sup>2</sup> /g)	4.81	4.78
10	Folding endurance, (No)	212	223

**TABLE—4**  
Pulping results and physical strength properties of kraft and kraft-AQ pulps  
at optimum condition

Sl. No.	Particulars	Process	
		Kraft	Kraft-AQ
1	Active alkali, (%) (as Na <sub>2</sub> O)	16	16
2	Rejects, (%)	1.12	0.30
3	Screened Yield, (%)	53.86	54.00
4	Unscreened Yield, (%)	54.98	54.30
5	Kappa number	29	22
6	AQ dose, (%)	—	0.1
7	Burst Index, (K Pa.m <sup>2</sup> /g)	7.12	7.25
8	Tensile Index, (Nm/g)	79.55	80.20
9	Tear Index, (mNm <sup>2</sup> /g)	7.51	7.02
10	Folding endurance, (No)	277	275

**TABLE—5**

Alcaper pulping of *C. sativa* with 13% alkali (as Na<sub>2</sub>O) with varying doses of AQ (0.0, 0.05, 0.1 and 0.2%) at 165°C followed by treatment with 3% H<sub>2</sub>O<sub>2</sub> with 3% alkali dose at 90°C for 90 minutes.

Cooking Parameters :

Ist Stage : Time from room temp. to 105°C = 30 minutes  
                   Time from 105°C to 165°C = 60 " "  
                   Time at 165°C = 180 " "  
                   Liquor to wood ratio. = 3.5:1  
 IInd Stage : Time from room temp. to 90°C = 25 minutes  
                   Time at 90°C = 90 " "

Sl. No.	AQ dose (%)	Kappa No.	Unscreened pulp Yield (%)	Reject (%)	Screened pulp Yield (%)
1	0.0	39	58.52	4.38	54.14
2	0.05	32	57.07	1.68	55.39
3	0.1	31	56.86	0.48	56.38
4	0.2	28	56.47	0.47	56.00

**TABLE—6**

Peroxide alkali (PA process) of *C. sativa* with 16% alkali (as Na<sub>2</sub>O) and 3% H<sub>2</sub>O<sub>2</sub> with varying dose of AQ at 165°C in presence of 1% MgSO<sub>4</sub> as a carbohydrate stabiliser.

Time from room temp. to 105°C = 30 minutes  
                   Time from 105°C to 165°C = 60 " "  
                   Time at 165°C = 180 " "  
                   Liquor to wood ratio = 3.5:1

Sl. No.	AQ dose (%)	Kappa No.	Unscreened pulp Yield (%)	Screening rejects (%)	Screened pulp Yield (%)	Residual alkali (gpl)
1	0.0	29	59.00	3.69	55.31	0.72
2	0.05	27	57.09	1.08	56.00	0.60
3	0.10	26	56.86	0.48	56.38	0.55
4	0.20	25	56.70	0.32	56.38	0.50



Table-5 (figure-2) indicate the effect of AQ during alcaper pulping of *C. sativa*. Different doses of AQ (0.0, 0.05, 0.1 and 0.2% on o.d. wood basis) were applied. These results clearly indicated that as the AQ dose increased the Kappa number showed a continuously decreasing trend. This decreasing trend was found to be quite pronounced upto an AQ dose of 0.1% and beyond that it was not so much pronounced. The screened pulp yield also showed a little increasing trend upto a limit of 0.1% AQ dose. Therefore, it is not much advantageous to use AQ dose beyond 0.1% limit (FDA limit).

Table-6 (figure-3) indicate the effect of different alkali doses (14, 16 and 18% as Na<sub>2</sub>O) during peroxide-alkali (PA process). The results indicated that as the alkali dose increased, the Kappa number reduced continuously (from 42 to 23), while the pulp yield and rejects showed a continuously decreasing trend. The screened pulp yield showed a marginal improving trend, thereby indicating that an alkali dose of 16% may be considered as optimum.

Table-7 (figure-4) showed the effect of AQ dose (0.00, 0.05, 0.1 and 0.2%, on o.d. wood basis) during peroxide-alkali (PA) Process, carried out at 16% alkali dose. These results clearly indicated that on increasing the AQ dose, the Kappa number showed a continuously decreasing trend, the magnitude of decreasing the Kappa number was found to higher upto an AQ dose of 0.1% and beyond that the effect of further increasing the AQ dose was not so much pronounced. The pulp yield showed marginal improving trend while the rejects showed a continuously decreasing trend.

Table-8 (figure-5) showed the effect of different doses of H<sub>2</sub>O<sub>2</sub> (1, 2, 3, and 4% on o.d. wood basis), during peroxide-alkali (PA Process) delignification. These results indicated that on increasing the H<sub>2</sub>O<sub>2</sub> doses, the Kappa number and screening rejects both showed a continuously decreasing trend, and pulp yield showed a continuously marginal increasing trend, but the magnitude of decrease in kappa number was found to higher upto a peroxide dose of 3% and beyond that the effect of further increasing the peroxide dose was not so much pronounced, therefore a peroxide dose of 3% may be considered as an optimum dose of

peroxide. The bleachability of alkali peroxide pulps were equivalent to the bleachability of kraft pulps and were superior to that of soda-AQ pulps. The yield gain was found to be directly proportional to peroxide dose upto a peroxide dose of 3%, and beyond that the pulp yield remains practically constant (slightly decreased). Therefore a peroxide dose of 3% may be considered as optimum to get better yields.

Table 10 to 11 (figure 6 to 9) showed the strength properties of both unbleached and bleached PA and AP pulps. The results indicated that on beating these pulps at different freeness level, all the strength properties i.e. burst index, tensile index and folding endurance increased upto a certain freeness level i.e.  $42 \pm 2$  °SR and beyond that they decreased, while tear index first showed little enhancement and then sharp decline. Therefore, beating should not be continued beyond a freeness level of  $42 \pm 2$  °SR to achieve maximum physical strength properties.

Table-12 (figure 8 to 9) showed the strength properties of bleached PA and AP pulps. The results indicated that the strength properties of bleached pulps were slightly lower than that of unbleached PA and AP pulps due to fibre degradation during bleaching.

On comparing the alcaper (AP) process with peroxide alkali process (PA). The screened pulp yield, screening rejects, brightness and physical strength properties of PA process were found superior to AP process. The alcaper pulps showed the physical strength properties (at a freeness level of  $42 \pm 2$  °SR) identical to those of kraft pulps and superior to those of soda pulps.

#### Conclusion :

Gases evolved by a pulp mill using the alkali peroxide processes are completely free of sulphur components. This is a definite advantage since sulphur odours are a major complaint in neighbourhoods of kraft mills. Eradication of sulphur air pollutants is one of the most important advantages of the alkali peroxide process over the kraft process, because no other system today can achieve great improvements in this area. Thus the cost of an air pollution control system is saved and much more satisfactory results are obtained,

TABLE-7

Peroxide delignification of *C. sativa* with varying dose of alkali (14,16 and 18% as  $\text{Na}_2\text{O}$ ) alongwith 3%  $\text{H}_2\text{O}_2$ , 0.1% AQ and 1%  $\text{MgSO}_4$  as a carbohydrate stabiliser.

Cooking parameters :

Time from room temp. to 105°C = 30 minutes

Time from 105° to 165°C = 60 „

Time at 165°C = 180 „

Liquor to wood ratio = 3.5:1

Sl. No.	Alkali dose (as $\text{Na}_2\text{O}$ ) (%)	Kappa No.	Unscreened pulp Yield (%)	Screening rejects (%)	Screened pulp Yield (%)
1	14	28	59.20	3.77	55.43
2	16	26	56.86	0.48	56.38
3	18	22	55.10	0.10	55.00

TABLE-8

Peroxide alkali delignification of *C. sativa* with 16% active alkali (as  $\text{Na}_2\text{O}$ ), 0.1% AQ and 1%  $\text{MgSO}_4$  alongwith varying dose of  $\text{H}_2\text{O}_2$ .

Sl. No.	Dose of $\text{H}_2\text{O}_2$ (%)	Kappa No.	Unscreened pulp Yield (%)	Screening rejects (%)	Screened pulp Yield (%)
1	1.0	29	58.85	3.45	55.40
2	2.0	28	57.95	1.95	56.00
3	3.0	26	56.86	0.48	55.38
4	4.0	24	52.15	0.15	52.00

(Table 9 Next Page)

TABLE-10

Strength properties of unbleached alkali-peroxide pulps of *C. sativa*.

Sl. no.	Dose of AQ (%)	Beating Time (min.)	Freeness (°SR)	Drainage time (seconds)	Burst index (k pa.m <sup>2</sup> /g)	Tensile index (Nm/g)	Tear index (m Nm <sup>2</sup> /g)	Folding endurance (No.)
1	0.0	0	17	5	1.28	28.47	6.41	6
		20	35	15	4.09	60.41	6.11	110
		28	40	18	4.43	63.10	6.57	154
		30	45	20	5.15	69.50	4.31	160
2	0.05	0	17	5	1.27	29.50	6.90	13
		20	35	15	5.08	64.64	6.10	151
		28	40	18	5.28	65.68	5.66	201
		30	45	20	6.50	71.28	5.51	225
3	0.10	0	17	5	1.77	28.79	7.18	19
		20	35	15	6.22	66.31	6.97	220
		28	40	18	6.48	73.21	6.82	275
		30	45	20	6.53	76.21	6.73	210
4	0.20	0	16	5	1.65	30.11	7.83	13
		20	36	16	6.14	64.28	6.66	163
		28	40	19	6.40	69.32	6.14	252
		30	45	20	6.38	70.71	5.15	263

**TABLE-9**  
Bleaching conditions and results of AP and PA Pulps of *C. sativa*.

Sl. No.	Particulars	AP	PA			
1	Unbleached pulp Kappa no.	31	26			
2	Chlorination stage (C)					
	Amount of Cl <sub>2</sub> added on pulp (%)	6.20	5.20			
	Amount of Cl <sub>2</sub> consumed on pulp (%)	5.88	5.10			
	Final pH	1.95	1.94			
3	Alkali Extraction stage (E)					
	NaOH added on pulp (%)	3.13	2.63			
	Initial pH	11.67	11.64			
	Final pH	10.27	10.30			
4	Chlorine dioxide stage (D <sub>1</sub> )					
	Amount of ClO <sub>2</sub> added on pulp (%)	1.0	1.0			
	Amount of ClO <sub>2</sub> consumed on pulp (%)	0.92	0.78			
	Final pH	3.6	3.8			
5	Peroxide stage (P)					
	Amount of H <sub>2</sub> O <sub>2</sub> added on pulp (%)	0.50	0.50			
	Amount of H <sub>2</sub> O <sub>2</sub> consumed on pulp (%)	0.48	0.44			
	Initial pH	10.0	10.9			
	Final pH	9.2	9.5			
6	Chlorine dioxide stage (D)					
	Amount of ClO <sub>2</sub> added on pulp (%)	0.03	0.30			
	Amount of ClO <sub>2</sub> consumed on pulp (%)	0.25	0.24			
	Final pH	3.3	3.5			
7	Bleaching losses (%)	10.0	9.5			
8	Bleached pulp yield (%)	50.19	50.78			
9	Pulp brightness (%)	81.0	83.0			
	Bleaching conditions :	C	E	D <sub>1</sub>	P	D <sub>2</sub>
	Consistency (%)	2.8	10	6	12	6%
	Temperature (°C)	27±5	55±2	70±2	60±2	70±2
	Time (minute)	30	120	180	180	180

TABLE-11  
Strength properties of Unbleached peroxide-alkali pulps of *C. sativa*

Sl.No.	Dose of AQ (%)	Beating time (min.)	Freeness (°SR)	Drainage time (Seconds)	Burst index (k pa.m <sup>2</sup> /g)	Tensile index (Nm/g)	Tear index (m Nm <sup>2</sup> /g]	Folding endurance (No)
1	0.0	0	11	5	1.64	28.37	4.22	7
		10	30	13	3.49	56.53	5.67	25
		28	40	18	4.94	63.50	5.31	167
		30	45	20	5.67	68.13	4.92	185
2	0.05	0	14	5	2.12	34.60	4.38	36
		8	29	14	3.86	45.30	6.37	115
		28	38	18	5.15	66.24	5.40	140
		30	45	20	5.95	70.21	5.28	190
3	0.10	0	15	5	2.62	45.35	4.62	50
		10	28	14	5.59	67.39	7.61	85
		28	38	18	6.65	75.47	7.24	255
		30	45	20	6.96	79.81	6.95	274
4	0.20	0	16	5	3.62	46.32	5.38	57
		10	29	14	5.66	97.37	6.81	90
		28	38	18	6.76	76.47	5.70	260
		30	45	20	6.86	77.81	5.35	266

TABLE-12  
Strength properties of bleached peroxide-alkali and alkali peroxide pulps of *C. sativa*.

Sl. No.	Process	Beating time (min.)	Freeness (°SR)	Drainage time (seconds)	Burst index (k Pa.m <sup>2</sup> /g)	Tensile index (Nm/g)	Tear index (mN.m <sup>2</sup> /g)	Folding endurance (No)	Brightness (Elrepho) (%)
1	PA	0	20	6	2.72	45.00	7.69	15	83.2
		18	35	13	4.72	67.21	6.72	236	83.0
		28	40	17	5.82	72.21	6.52	250	82.5
		30	45	18	6.38	73.03	5.42	260	82.0
2	AP	0	16	5	2.15	36.50	7.02	55	82.2
		10	30	15	5.23	64.52	7.48	225	82.0
		29	40	17	5.73	68.23	6.12	254	81.5
		30	45	18	6.12	70.73	5.48	250	81.0

Only caustic soda has to be recovered which means that new combustion and causticising techniques can be used such as fluidized bed smelt causticising.

The production cost of an alkali peroxide pulp mill probably be similar to that of a kraft pulp mill, since the cost of AQ, H<sub>2</sub>O<sub>2</sub> and extra soda used is offset by the increase in yield and the decrease in maintenance costs due to less corrosive nature of soda cooking liquor compared to kraft cooking liquor.

For the modification of a existing kraft mill into an alkali peroxide mill, the only additional equipment is the bleaching type tower for the H<sub>2</sub>O<sub>2</sub> treatment and the in line refiner for certain pulp wood species. These are not considerably higher than the cost of the pollution abatement equipment.

In conclusion, the alkali peroxide process is a desirable alternative to the kraft process. The substitution does not involve high capital investments and the pulp produced has the same characteristics as kraft mill. With a brighter colour which will make it a product that is easier to market. It uses AQ upto the level authorised by the FDA (0.1%) for pulps made for the food packaging industry.

Finally and most importantly, it completely solves the problem of air pollution caused by sulphur components.

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