No Chlorine Bleaching of Bagasse and Hardwood Kraft Pulps to 80+ISO

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ABSTRACT: *Total chlorine free (TCF) bleaching involving Oxygen, Peroxide and hemicellulolytic enzyme xylanase produced a pulp of 80+ISO brightness with bagasse kraft pulp and hardwood kraft pulp. The various bleaching sequences and their implications with respect to achieving the target brightness have been considered. The quality of TCF pulp was comparable to that of conventional pulps. Chelation, acid wash and lignin activation treatments considerably improved the bleachability of bagasse and hardwood pulps.*

KEY WORDS: *Chlorine free bleaching, Chlorinated organics, Peroxide, Oxygen delignification, Lignin activation, Sequestration, Brightness, Enzymatic hydrolysis, Kraft chemical pulp.*

INTRODUCTION

Ever since the discovery of the harmful nature of chlorinated organic subtances in the traditional bleaching presumably causing biological disorder in the higher organisms, the environmentalists and ecologists have started to display their disapproval publicly (1). In the foreseeable future the corporate, environmental and governmental activities concerning the chlorinated organics emanating from the kraft pulp bleaching processes, may even control the marketing strategy of pulp and paper products (2). Systematic studies have been conducted (3) on the effect of chlorinated organics and the findings have forced many western countries to formulate new environmental regulations (4). This has persuaded many mills to upgrade their pulping and bleaching methods to comply with the new regulations. The term Total chlorine free (TCF) Bleaching has gained significant familiarity in the pulp and paper industry in the recent years. Pearson.J., (5) presents the current status of production of TCF pulps from a European perspective.

Major modifications in pulping processes and bleaching methods are being designed in order to achieve the required brightness with TCF (6). Various chemical pre-treatments to render the pulp with enhanced bleachability are being considered. Even though there is no substantial evidence to prove that the chlorinated compounds generated in the bleaching are harmful to human life, it has been found (7) that they are detrimental to other organisms. Therefore, low chlorine/ no chlorine bleaching methods are being increasingly adopted in spite of the exorbitant cost of the product when compared with the traditional bleaching methods. (8,9).

In India, the awareness towards the environmental impact of the chlorinated compounds in the effluent has started growing. The pressure on the paper industries will be soon mounting due to the fact that the Indian environmental authorities have stipulated the discharge limits of chlorinated organics in their recent revised paper mill effluent specifications.

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Presently, hardwoods particularly Eucalyptus is being used as the chief woody raw material in the country. Conventional pulping and bleaching methods are only followed in most of the of paper mills. However, the fast depletion of the forest resources for the woody raw materials has made the Indian paper industry to look for non-wood substitutes, out of which, bagasse has emerged as the most potential raw material for paper making. Extensive research work to explore the potential of bagasse has been carried out.

This paper discusses about the various possibilities, schemes and bleaching sequences that do not use either elemental chlorine or chlorine containing compounds for bleaching the kraft pulp from bagasse and eucalyptus. The behaviour of bagasse chemical pulps and eucalyptus chemical pulps towards TCF bleaching are briefly compared.

It is anticipated that the TCF bleaching in future will be dominantly controlled by the oxygen based reagents like molecular oxygen, hydrogen peroxide and ozone (10). Keeping this in view, this work on TCF bleaching of bagasse and hardwood describes probable sequences employing oxygen, and peroxide since, ozone is yet to be realised in the Indian context. Besides, the benefits of utilising hemicellulase enzymes as brightness boosters are also briefly discussed.

EXPERIMENTAL

Pulp

Kraft unbleached, screened chemical pulps of hard wood (E. Hybrid) and bagasse were collected from our mill. The pulps were thoroughly washed over 250 mesh, thickened in a laboratory hydro extractor and stored in polythene bags. The characteristics of the unbleached pulps are shown in the Table 2. The hard wood pulp is processed in typical plant digester with 1600 H factor,

Table-1.

General bleaching conditions

Parameter	Oxygen O	Enzyme X	Acid Peroxide* AP	EOP	Q	QAP	Alkaline Peroxide P
Consistency,%	8	8	10	8	3.5	10	8
Oxygen pr., MPa	0.50	-	-	0.50	-	-	-
Sodium hydroxide,%	2	-	-	2	-	-	Var.
Peroxide, %	-	-	1.0	2.0	-	1.0	Var.
EDTA,%	-	-	-	-	0.2	0.2	-
Temperature, °C	120	50	85	100	85	85	90
Reaction Time, min	30	120	60	60	30	60	240
Exit pH	10-20	4.5	5	10-12	5	5	11.0-11.5

* 500 ppm of Sodium molybdate was maintained
Q- Sequestration
Deviation from the above conditions if any is referred in the text itself

Table-2.

Pulp Characteristics

Pulp	Kappa Number	Brightness % ISO	Viscosity cPs
Bagasse Unbleached Pulp	9.3	50.4	30.6
Bagasse Oxygen prebleached pulp	3.8	65.2	28.1
Hardwood Unbleached Pulp	16.2	25.9	9.4
Hardwood Oxygen prebleached pulp	7.1	47.9	8.4

and the bagasse pulp is processed in continuous digester with a retention time of 20 min.

Laboratory bleaching experiments

The oxygen delignification (O) and peroxide reinforced oxygen delignification (EOP) were performed in electrically operated programmable rotating stainless steel vessel with 500 gms (o.d.) pulp. Molecular oxygen gas was injected from an oxygen cylinder through a specially made adopter to the desired experimental pressure. To enhance the mixing, a stainless steel shredder was placed inside the digester. Throughout the oxygen delignification surplus O_2 pressure was maintained. Prior to the oxygen delignification the pulp was manually mixed with sodium hydroxide and magnesium carbonate as the viscosity protector. The standard conditions maintained during the oxygen delignificaiton are given in Table 1. After the Oxygen treatment the pulp was washed and thickened in the hydro extractor.

Peroxide (P) bleaching was carried out in polythene bags. The initial exploratory tests were conducted with 10 g (o.d.) pulp. The pulps were incubated in a thermostatic water bath at a desired temperature. Peroxide and sodium hydroxide were mixed manually. The bleaching conditions are given in Table 1. Similarly acid peroxide treatment (AP) enzyme treatment (X) and sequestration (Q) were also performed in polythene bages.

For enzyme pretreatment a pure commercial xylanase enzyme was used. A constant dosage of 8 XU/g (XU = Xylanase units) was administered and the pH was maintained at 4.5 throughout the treatment period.

In AP stage, to enhance the delignification a molybdenum catalyst in the form sodium molybdate (500 mg/Kg) was added along with the peroxide. pH was maintained at 5.0. Sequestration was carried out 3.5 consistency with 0.2 % EDTA at 85° C for 30 minutes. The Q treatment was always preceded by an acid wash. The acid treatment was done at room temperature by keeping the pulp at pH 5 (3 % consistency) after which the pulp was dewatered. The (QAP) stage was performed by combining the Q treatment with the AP stage at 10 % consistency. Washing was not done after the Q treatment while the QAP pulp was washed before proceeding to subsequent bleaching stages.

Analysis

Pulp kappa number, brightness, viscosity and strength properties were determined according to Tappi standards. Beating of the pulp was carried out on never-dried pulps in a PFI mill. Brightness and other optical properties were measured using an Elrepho brightness tester. The pulp brightness pads were made at pH 5.

RESULTS AND DISCUSSION

Sequestration and Acid washing

Among the various non - chlorine compounds effectively used for TCF bleaching peroxide has come out as one of the most frequently used chemical. In recent years peroxide is increasingly being utilised as delignifying agent as well as in the brightening stages. However, kraft pulp contains transition metal ions such as iron, copper, and manganese which induce decomposition of peroxide leading to substantial loss of chemical availability for bleaching. This connot be afforded since, peroxide is one of the most expensive chemicals. Therefore, an effort was attempted to destroy the metal ions.

Table-3.

Preliminary exploratory experiments for selecting the ideal conditions for peroxide bleaching of hardwood and bagasse kraft pulps

		Peroxide Bleaching			
Acid wash 5.0pH	Chelation EDTA,%	peroxide** uptake %	Reaction Temp. °C	Reaction Time min	Brightness %ISO
Bagasse					
NO	NO	1.12	60	120	64.5
NO	NO	1.94	90	240	72.3
NO	0.20	1.84	90	240	75.2
NO	0.60	1.42	90	240	75.9
YES	0.20	0.54	60	120	66.2
YES	0.20	1.28	90	240	77.0
YES	0.60	1.31	90	240	77.8
Hardwood					
NO	NO	1.40	60	120	46.2
NO	NO	1.64	60	240	52.1
NO	NO	1.80	90	120	53.1
NO	NO	1.96	90	240	57.9
YES	0.20	1.18	60	120	49.2
YES	0.20	1.43	60	240	55.2
YES	0.20	1.73	90	120	57.8
YES	0.20	1.88	90	240	62.0

*** Peroxide addition 2.0%*

Improving the bleachability by sequestration

It is well known that mechanical pulps are treated with sequestering agents like DTPA, EDTA, and DTPMP etc. to remove the metal ions from the pulp. These chelating agents are some times referred as peroxide stabilizers since they remove the metallic ions by complexing with them (11). Table 3 shows the results obtained from peroxide bleaching preceded by the EDTA treatment. The results clearly indicate that the chelation boost the brightness from 72.3% ISO to 75.2% ISO. Further it can also be observed that there is no appreciable gain in the brightness by increasing the EDTA dosage from 0.2 % to 0.6 %. Therefore for further experiments the dosage of EDTA was fixed at 0.2%.

Another interesting feature in the peroxide bleaching (Table 3) is that, increasing the bleaching temperature (90° C) and time (240 min) considerably enhances the brightness achievement. This may presumably due to the enhanced reactivity of perhydroxyl ions available for bleaching. Therefore, we opted these bleaching conditions in the subsequent peroxide bleaching experiments. Table 3 also features the effect of the acid treatment before the chelation. It has been reported that the removal of metallic ions can also be achieved by the simple acidification (12).

While the acidification removes the metal ions, it also removes the magnesium ions at low pH which again necessitates the addition of magnesium sulphate during the peroxide bleaching. To avoid this the acidification was done at pH 5 at 3% consistency. There was a net gain of 5 points in the final brightness (Acid-Q-P) by the acidification before the Q stage. Consequently further experiments with Q stage were always preceded by the acidification step.

Pre-bleaching Processes
Lignin activation

It has been frequently emphasized that reduction in the lignin content is the key to achieve high brightness in the bleaching. This holds good in the case of TCF bleaching also. A variety of pretreatments have been suggested to achieve the maximum reduction in the lignin content which is indicated by the reduction in the kappa number (13,14). Hydrogen peroxide has been shown to have a dual role in bleaching. It works as a delignification agent in acidic medium. In alkaline medium it brightens the pulp by removing the chromophoric groups. Therefore, in our TCF bleaching of bagasse and hardwood pulps we have used acid peroxide delignification (AP) catalysed by sodium molybdate. In our earlier studies we optimised the conditions required for achieving maximum delignification. Those conditions are given in Table 1. Since, AP stage is performed at pH 5 and 85° C the Q stage was carried out along with the AP stage to retard the decomposition of peroxide by heavy metals, This step is referred as (QAP). Sodium molybdate was added with peroxide to improve the selectivity of peroxide treatment.

Oxygen delignification

Oxygen delignification has been acclaimed to be the most important stepping stone in the non-chlorine bleaching because of its economy and its efficiency in the primary removal of the residual lignin in the unbleached kraft pulps. For our TCF bleaching of bagasse and hardwood optimisation of the bleaching conditions (Table 1) were performed by using the Plackett and Burman (15) experimental design. The design of experiments have taken care of the most influential factors in the oxygen delignification to achieve maximum lignin removal and with minimum carbohydrate loss.

In our oxygen delignification we achieved 60 % reduction in the kappa number of the bagasse unbleached pulp and 59 % for hardwood pulp. To achieve this we used the following empirical relationship derived from Plackett and Burman design.

Hardwood pulp

Kappa Number = 7.35-0.020 (Time-37.5)-0.036 (Temp-110)-0.345 (Alk-4.0)-0.053 (Pr-6.5)

Bagasse pulp

Kappa Number = 5.4-0.02 (Time-37.5)-0.05 (Temp-110)-0.6 (Alk-2)

The characteristics of the oxygen prebleached pulps are given in Table 2. It can be observed that bagasse pulps and the hardwood pulps are delignified with appreciable selectivity (about 10% loss in viscosity). To maintain this selectivity a constant dose (0.5%)

of magnesium carbonate was always added to the pulp prior to oxygen delignification.

SHORT TCF SEQUENCES TO ACHIEVE 80% ISO

Typically TCF pulps are being made at around 80% ISO and achieving still higher brightness levels of 90% ISO is not yet commercially realised (16). However, it may be possible to achieve very high brightness by combining ozone and other modern pulping techniques like modified continuous kraft pulping. In the present context we have aimed at 80% ISO. Table 4 and 5 present a variety of TCF sequences consisting of O, AP, Q, P and peroxide reinforced alkaline oxygen extraction (EOP). These sequences were performed under respective optimum conditions.

Table-4.

Short TCF sequences for Bagasse kraft pulp

	Sequence	Brightness %ISO	Peroxide Requirement Kgs/BDMT
	Unbleached	49.4	-
	Q	65.6	-
Set I	$O(AP)EP_1$	79.9	5.0
	$O(AP)P_1P_1$*	82.9	13.4
	$O(AP)P_2$	82.9	22.3
Set II	$OQP_{0.5}$	77.7	2.1
	OQP_1	79.9	7.9
	$OQP_{1.5}$	83.6	13.5
Set III	$QP_{1.5}$	72.7	13.5
	QP_3	75.6	29.9
	$Q(EOP_1)$	76.8	10.0
	$Q(EOP_2)$	80.9	13.4
	$Q(EOP_1)P_{0.5}$	77.8	13.4
	$Q(EOP_1)P_1$	79.6	17.2
	$Q(EOP_1)P_2$	81.4	23.1
Set IV	(EOP_2)	76.8	20.0
	$(EOP_2)P_{0.5}$	78.9	23.1
	$(EOP_2)P_1$	80.5	27.5
	$(EOP_2)P_2$	83.4	32.0

Suffix to 'P' indicates peroxide charge in %
**Peroxide bleaching at 60°C for 120 min*

Bagasse kraft pulps

Table 4 illustrates the effectiveness of these sequences with bagasse kraft pulp. The first set of experiments (Set 1) relates to the bleaching sequences involving oxygen followed by acid peroxide and alkaline peroxide {O (AP) P }. Two out of three sequences {O (AP) P_1P_1, O (AP) P_2} presented, yield 80% ISO brightness. Although oxygen delignification is relatively superior to acidic peroxide delignificaition, it has been found that the phenolic-biphenyl structures present in the kraft residual lignin are unreactive to oxygen, but are easily oxidized by molybdate activated acid peroxide (17). Therefore it was felt necessary to have the AP stage next to the oxygen. It can further be noted that 2 stage peroxide {O (AP) P_1P_1} for 4 hours at 60° C is similar to single stage peroxide {O (AP) P_2} at 90° C.

Table-5.

Short TCF sequences for Hardwood pulp

	Sequence	Brightness %ISO	Peroxide Requirement Kgs/BDMT
	Unbleached	25.4	-
	O	47.9	-
Set I	$O(QAP)P_1$	72.1	14.0
	$O(QAP)P_2$	75.5	24.0
	$O(QAP)P_3$	80.7	34.0
	$O(QAP)(EOP_2)$	74.3	24.0
	$O(QAP)(EOP_2)P_1$	78.3	34.0
Set II	$O(EOP_2)$	64.0	20.0
	$O(EOP_2)P_2$	67.4	40/0
	$O(EOP_2)PQ_1$	73.5	30.0
	$O(EOP_2)QP_2$	75.1	40.0
	$O(EOP_2)QP_3$	76.5	50.0
	$O(EOP_2)QP_1P_1$	79.1	40.0
	$O(EOP_2)QP_2P_1$	79.6	50.0
Set III	$OQ(EOP_2)$	70.0	17.0
	$OQ(EOP_2)P_2$	75.7	37.0
	$OQ(EOP_2)(AP)P_1$	82.4	30.0

Suffix to 'P' indicates peroxide charge in %

The second set of experiments (set 2) also consists of sequences that begin with oxygen delignification. These sequences are shorter than those of previous set (set 1) and contain Q stage after oxygen. The highest brightness of 83.6% ISO was obtained with 1.5% peroxide in the P stage (OQP). Interestingly, it may be said that the effect of Q is so significant that AP stage in the set 1 can be replaced by Q.

Eventhough the AP stage of is performed at 5 pH it was not capable of trapping the metal ions. On the contrary, acidification followed by EDTA treatment removes most of the metallic ions which is presumably responsible for higher brightness and less peroxide consumption in these bleaching sequences.

Further experiments were (set 3) performed with sequestration (Q) of the unbleached pulp. Even though the unbleached pulp is subjected to acidification and chelation, still the target brightness was not achieved (Table 4) even with a very high dosage of peroxide (as high as 3%). This sequence ($QP_{3.0}$) could yield a pulp of 75.6% ISO. Therefore, the Q treated unbleached pulp was subjected to alkaline oxygen extraction with peroxide reinforcement (QEOP). Among the sequences given in set 3 Q(EOP_2) is the shortest ever to produce a pulp of 80.9% ISO. Again the reason for this significant gain in brightness by a single step is due to the high reduction of lignin content.

The next set of experiments (set 4) were performed with (EOP) as the first stage.

The (EOP) stage was performed at 100 deg. C against 120 in the O_2 delignification to avoid the decomposition of peroxide at higher temperature. Because of the high content of heavy metal ions in the kraft brown stock, (EOP) cannot be efficiently used as first stage without eliminating the metal ions. (18). This fact is highlighted by the sequences in the fourth set of experiments where it is observed that without Q treatment EOP_2 could give only 76.8% ISO against 80.9% ISO with Q treatment (set 3). The EOP stage without Q pretreatment had to be subsequently followed by additional peroxide stage to attain the target brightness.

Hardwood kraft pulps

Table 5 illustrates the various sequences atempted for hard wood. Since the kappa number of the unbleached wood pulp was high (16) and the brightness was very low when compared to bagasse, it was difficult to attain high brightness for hardwood. In the case of hard wood bleaching EDTA was added along with AP stage (QAP) which avoided a separate acidification and a separate chelation stage. In the first set of experiments carried out for hardwood pulp the highest brightness (80.7) was obtained with O (QAP) P_3.

Set 2 illustrates the ineffectiveness of the O(EOP) sequences devoid of Q treatment. OQ (EOP) P_2 could reach 75.7% ISO while O (EOP) P_2 could give only 67.4% ISO. Even though this involves a second stage oxygen bleaching, it was not efficient enough to boost the brightness. Introducing a Q stage after (EOP) followed by alkaline peroxide stage could improve the brightness to some extent. Even then two stage peroxide bleaching was required to attain the target brightness.

Among the three Q (EOP) sequences studied (set 3) only OQ (EOP) APP_2 gave 82.4% ISO. OQ (EOP) P_2 did not achieve 80+. due to the higher lignin content. Hence the introduction of (AP) stage in the above sequence could improve the brightness to 80+.

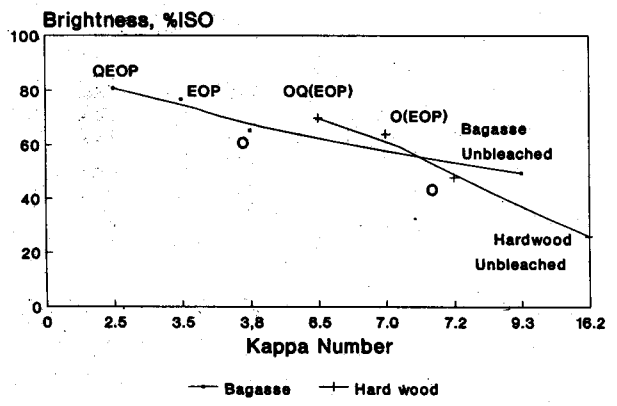
TCF bleaching of bagasse and hardwood kraft chemical pulps - A Comparison

From the foregoing discussion we observe that without the assistance of chlorine or chlorine containing compounds it is possible to bleach both bagasse and hardwood pulps to 80 + ISO with oxygen and peroxide. This study has produced considerable insight over the chlorine free bleaching of the bagasse and hard wood pulps.

Bagasse pulps possess a set of definite advantages over hardwood pulps with respect the bleaching aspects in TCF sequences. Fig- 1 illustrates the effect of kappa number reduction on both pulps. Hardwood pulp is more stubborn than bagasse pulp. Even after 2

stage oxygen treatment with Q treatment the brightness could not be enhanced since the kappa number was not sufficiently lowered down in the case

Fig.1 Kappanumber Vs Brightness



of hardwood pulp. On the other hand a direct (EOP) with Q treatment of unbleached bagasse pulp was very much efficient enough to reach the target 80+ ISO. The brightness of O (EOP) hardwood pulp was similar to the direct O pulp of bagasse but the kappa number is very much higher (6.5) than that of bagasse O pulp (3.8). This is the reason for higher peroxide consumption in the subsquent P stages in the hardwood. Though the oxygen delignified hardwood pulp has a kappa number of 7 in comparison to the kappa number of unbleached bagasse pulp of 9.4 under the same bleaching conditions bagasse gives higher brightness than hardwood.

It has frequently been stated that to achieve TCF brightness levels, the kappa number of the brown stock must be reduced to lowest possible in the digester itself. To achieve this, a number of processes such as modified continuous cooking (MCC). Rapid displacement Heating process (RDH) and combined oxygen - extended delignification process have been commercially well exploited throughout the world. However, these process modifications in the kraft pulping required enormous changes in the conventional plants and in turn high capital investment. In contrast, bagasse kraft pulping does not require any of these systems. Bagasse is easily pulped to a very low kappa number (9-10) lower than the present level of MCC kappa number (12-13) of hardwood pulps. This low kappa number can be achieved with less amount conventional pulping chemicals in extremely short pulping time (as low as 20 min) in continuous digesters. This is not possible with the hardwood with the conventional pulping.

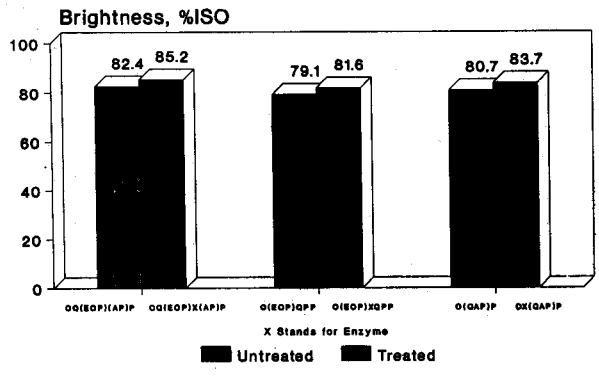
Further, the high kappa number of the hardwood pulp requires more bleaching chemicals. This shoots up the cost of the processes per ton of the pulp. Table 6 shows the peroxide requirement for TCF sequences of bagasse and hardwood pulps. On an average the hardwood sequences required 15 kgs of peroxide more than that of bagasse sequences. Therefore, with respect of TCF bleaching bagasse kraft pulp possesses definite advantages than hard wood pulp.

Improving the bleachability of hardwood pulps with enzyme pretreatment

The use of hemicellulolytic enzymes especially xylanases to enhance the bleachability of kraft pulps was first discovered in 1986 (19). The enzymes are very much useful in increasing the brightness ceiling and decreasing the bleaching chemical requirement (20). With enzymes it is possible to achieve the same brightness with reduced chemical. The enzyme hydrolyse the hemicellulose portion of the pulp. This hydrolysing property of the xylanse enzymes are very much essential for hardwoods where the delignification is more difficult than bagasse pulp.

Fig. 2 shows the effect of the enzymes on the bleachability of hardwood pulps. By introducing the xylanase enzymes in the selected sequences (Table 5) the brightness was increased significantly by 3 points. This shows that the brightness of 80 + ISO can be achieved easily with reduced peroxide requirement with xylanse pretreatment, for hardwood kraft pulps.

Fig.2 Effect of Xylanase enzyme on the bleachability of hardwood pulp



Pulp Quality

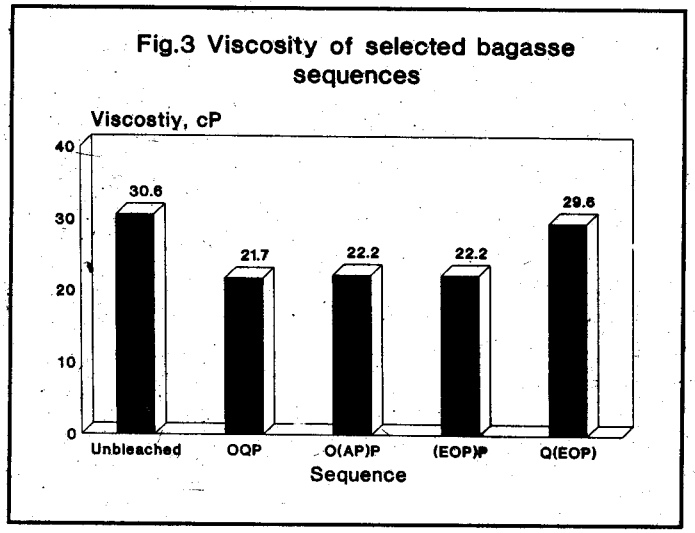
Pulp quality of TCF pulps can be measured in terms of pulp strength carbohydrate retention and cleanliness. Table 6 presents the pulp properties of

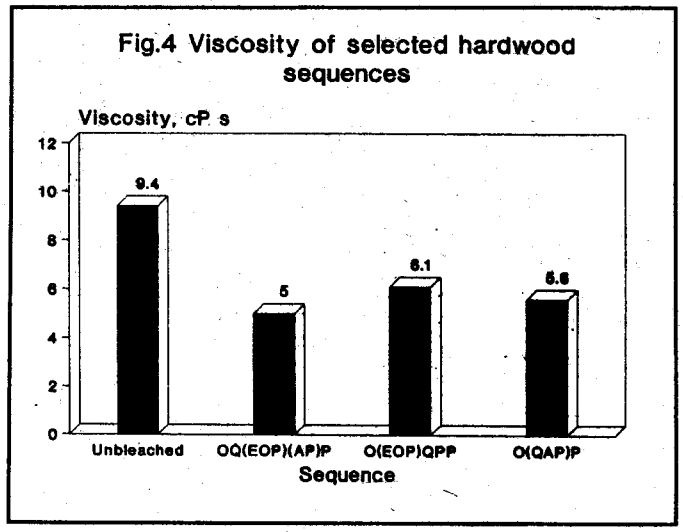
Table-6.

Propeties of Selected TCF swquences

Sequence	Pulp Yield %	Final Brightness %ISO	Peroxide Kgs/BDMT	Strength Properties at 300 ml CSF: Tensile Index Nm/g	Tear Index mN.m²/g	Burst Index kPa.m²/g
Bagasse Pulp						
O(AP)P	94.8	82.9	22.3	69.90	6.60	4.66
OQP	93.1	83.6	13.7	67.05	6.46	4.37
Q(EOP)	96.4	80.9	13.4	73.43	6.35	4.84
(EOP)P	94.4	80.5	27.5	73.53	6.31	4.73
Hardwood Pulp						
O(QAP)P	95.1	80.7	30.4	58.73	5.78	3.46
O(EOP)QPP	94.3	79.1	40.6	58.33	5.84	3.42
OQ(EOP)(AP)P	94.4	82.4	30.3	67.65	6.48	4.23

selected sequences. The results indicate the bonding strength and fibre strength are comparable to conventionally bleached pulps. Figures 3 and 4 illustrate the effect of various TCF bleaching sequences on viscosity of the bleached pulps of hardwood and bagasse. In the case of bagasse sequences there is about 10% drop in the viscosity of final bleached pulp.





The viscosity of the Q(EOP) sequence is significantly retained due to the pretreatment with the chelant. It is reported that during the oxygen delignification the metallic ions catalyze intermediate species that cause carbohydrate degradation (21). The higher yield may also be attributed to the Q treatment. Pulp cleanliness of TCF pulps were found to be poorer than the conventionally bleached pulps, but on refining this problem disappears into insignificance.

SUMMARY

The study on bleaching of conventional hardwood kraft pulp and bagasse kraft pulps to 80 + ISO without molecular chlorine and chlorine containing compounds has revealed the following--

1. TCF bleaching of bagasse pulps and hardwood pulps has completely ruled out chlorinated organics.
2. The chemical pretreatment with acid peroxide and chelation improved the pulp bleachability significantly.
3. Without alkaline oxygen delignification it is impossible to perform TCF bleaching economically.
4. In TCF bleaching the kappa number of the unbleached pulp seems to be chief determining factor for reaching high brightness.
5. Bagasse pulps are more readily bleachable than hardwood pulps without major process modifications.
6. By combining oxygen and peroxide it is possible to

reach the target brightness of 80 + ISO.

7. The bleaching chemical cost for bagasse sequences are far less than that of hardwood sequences.
8. The bleaching chemical cost of hardwood sequences can be considerably reduced by the effective usage of xylanase enzymes.
9. The bleaching cost of the TCF sequences are higher than that of the conventional bleaching methods.

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