

“Alkaline Chlorine Dioxide Bleaching Of Cloned Eucalyptus Hybrid Wood 2013 and Its Environmental Impact ”

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Abstract: The bleaching chemistry indicates that pH affects the effectiveness of chlorine dioxide treatment and the standard recommendations has been to maintain a final stage pH range for brightening with chlorine dioxide between 3.5 and 4.0. But we used 16% & 17% TAA cooked Clone **EH2013** of kappa number 18.7 & 17.4 without Oxygen Delignification (ODL), were bleached in Acidic and Alkaline pH initial chlorine dioxide (D₀) stage, followed by Caustic reinforced Hydrogen peroxide (Ep) and final Chlorine dioxide (D₁) stage of bleaching. At constant bleaching condition both EH2013 pulps show these alkaline pH bleaching methods can improve the pulp bleachability without affecting pulp strength properties, optical properties, and physical properties and improved effluent characteristics. The Alkaline pH bleached pulp final brightness 85.7 %ISO (16% TAA) and 86.5%ISO (17% TAA) are well compared to Acidic pH final brightness 83.4 %ISO (16% TAA) and 84.4%ISO (17% TAA) initial chlorine dioxide bleaching and followed by extraction reinforced Hydrogen peroxide and final Chlorine dioxide bleaching. The fiber length, width and curl index of Acidic and Alkaline pH bleached pulp has not shown any distinct variation, but alkaline pH bleached pulp has shown slightly higher than Acidic pH bleached Pulp. Both 16&17% TAA cooked pulps filtrate analysis of the Alkaline pH Do stage, shows lower Colour (14.6 & 15.4%), Total Dissolved Solids (10.7 & 17.9%) and COD (14.2 & 18.0%) than Acidic pH Do bleaching filtrate. Based on results from the Acidic and Alkaline pH bleaching of EH2013 pulp , we found that the optimum pH for initial Do and final D₁ chlorine dioxide bleaching stage should be operated with a final pH close to alkaline, when a typical chlorine dioxide charge is applied and its effluent characteristics shows lesser inorganic load when compared to acidic effluent .

Keywords: alkaline bleaching, acidic bleaching, clone EH, Chemical Oxygen Demand, Fiber length.

I. Introduction

Pulp and paper making is a resource-depletion process that consumes large amounts of energy, water, trees and fillers. It is a mature industry that is innovative and adapts intermittently to technological change in order to remain competitive and penetrative in the National and International market. The emergence of this technology took place during the latter half of the nineteenth century, a time when there was little thought given to the possible detrimental effects of industrial pollution on the environment or human health. In the United States, pulp and paper mills are now considered the nation's third largest polluter (1). In Canada, it has been estimated that this industry is responsible for 50% of all the waste dumped into the nation's waters (2) and also accounts for approximately 5.6% of the common air contaminants from known industrial sources (3)The emerging technologies exist for substantially reducing emissions, particularly those that are a great risk to present and future generation. However, pulp and paper mills represent capital expenditures in the high hundreds of millions of dollars, and retrofitting a pulp and paper mill with new process technologies for pollution abatement regularly costs additional hundreds of millions of dollars. Such huge expenditures put pulp and paper mills at a disadvantage with competitors with Developed countries without stringent effluent controls. The implementation of environmental protection will have to proceed in a manner that sustains the economic health of the pulp and paper industry, yet ensures human health and environmental quality.

To tackle this problem in a cost-effective manner it is necessary to understand the nature of the problem, and identify the specific components that endanger human health and environmental quality. It is then possible to choose and install new process technologies to prevent the production of toxic effluents. Alternatively, depending upon economic circumstances and the age of the mill, it may be more cost-effective to add an end-of-pipe waste water treatment system. There is a large degree of variation in the pulping and bleach plant technologies used in mills. Accordingly, the solution for one mill cannot be applied to the environmental problems of the whole pulp and paper industry.

Most of the world's bleached pulp is presently treated using oxygen delignification. Oxygen delignification is a process which uses oxygen and alkali to remove a substantial fraction of the lignin that remains after pulping. During oxygen delignification, it has been confirmed that the number of phenolic hydroxyl groups and carboxyl groups in the lignin decreases and the number of carboxylic acid groups

increases. The final degradation products from oxygen delignification are predominately organic acids and carbon dioxide.

Physical properties of paper depend both on fiber to fiber bonding and on the intrinsic fiber strength of the pulp. However, reductions in pulp viscosity are usually significant only at low freeness values when the paper is well bonded and fiber failure determines paper strength. Moreover, because high pressures are involved in oxygen delignification, the cost of an oxygen system can require a significant capital investment. The random attacks on the cellulose chain decrease the average length of the cellulose, as indicated by a decrease in pulp viscosity, which if excessive, leads to the loss of pulp strength.

It is easier to delignify pulps with high rather than low initial kappa numbers. It has been reported that southern hardwood kraft pulps with high initial kappa number have lower resistance to oxygen delignification and a higher reaction rate compared to pulps with low initial kappa number (4). The reason for this observation is that the kappa number represents a combination of different oxidizable components: lignin, nonlignin oxidizable structures, and hexenuronic acids (HexA) (5), and the relative contribution of HexA, which are unreactive under standard oxygen delignification conditions, decreases with increasing kappa number. Also certain portions of the adsorbed compounds adhere very firmly to the Cellulose fibers and behave almost like native lignin with regard to the action of strong mineral acids and mild oxidation. This can stimulate higher lignin content in analysis (HermannF.J.).

The pulp bleachability of initial Chlorine dioxide treatment would be directly related to the amounts of phenoxy groups present in the lignin as per the literature. This result was significant since most bleaching text books (6, 7) assert that the ClO_2 bleaching chemistry occurs primarily via phenoxy groups and that this unit in lignin controls pulp bleachability. To define the influence of pH on ClO_2 bleaching of Eucalyptus pulps, a Laboratory cooked pulps of 16% and 17% white liquor (TAA) addition was prepared, analysed, and bleached without Oxygen Delignification (ODL) stage via DoEpD₁ sequence. The present bleaching study relates to a process for the delignification and bleaching of an aqueous lignocellulosic pulp under acidic and alkaline pH conditions in the initial Chlorine dioxide bleaching sequence and its environmental impacts. The changes in pulp bleaching at acidic and alkaline pH bleached pulp were evaluated to determine the bleachability of Cloned EH2013.

Stringent regulation of pulp and paper mill discharge by nodal authorities and public awareness will necessitate large capital expenditures by the industry. Consequently, these regulations will ensure modified pulping, bleaching, improved environmental quality, and a reduction of the risk to human health that is posed by this vital industry.

Research and the development of new processes and techniques to curtail the release of filtrates from pulp mills are following approaches. The first strategy is the development of new pulping processes with emphasis on improved delignification without ODL, and the replacement of Sulphuric Acid for bleaching. The second approach is the development of new alkaline bleaching processes, particularly individual or mixed wood species have advantages for effluent characteristics. These finding has been confirmed more recently both in the Laboratory (8) and on a mill scale (9).

II. Experimental

Raw material preparation: Cloned Eucalyptus Hybrid 2013 are developed and planted an experimental scale in TNPL plantation area for high yield and quality pulping purposes. Economically, this is an important species for the tropical farmers, to whom this provides an insurance against agricultural failure. In TNPL, The breeding programs of various wood clones were established with IFGTB, Coimbatore. The species of EH2013 were developed and may introduce into farm forestry under the TNPL intensive plantation, and this has attracted the attention of farmers in drier tracts of the state, due its adaptation to the arid conditions.

Four year old Clone EH2013 tree was cut, debarked, cut into wood logs and chipped in a mill Disc chipper and screened in a standard laboratory Chip screen and the accepted chips were air dried at room temperature. After getting constant moisture, the chip are packed in a polythene bag and stored for a day to get homogeneous moisture of the chip before cooking.

Pulping: The chips were pulped (alkali charge 16 % and 17% as Na_2O , Liquor to wood ratio L: W= 2.8:1 cooking temperature: 165⁰C, time: 65 minutes) in a Laboratory bomb digester. At the end of cooking, the contents of the bomb were discharged into a bowl followed by sequential washing with DM water, disintegrated in a rod mill for 20 minutes, screened on a flat - slotted laboratory screen (slot width 0.15mm), centrifuged, and then granulated. Total pulp yield, amount of screen rejects, kappa number and black liquor properties were determined using TAPPI standard methods. After dewatering and fluffing, kappa number, percentage rejects, and total yield were determined. The unbleached pulp properties were listed in Table: I. The lack of certain excess of free alkali in the final stage of the cook can cause a shift of the dynamic equilibrium between the

decomposition of the wood chips and the sorption leads to increase desorption of the organic substances dissolved in the cooking liquor.

The Cooked and screened EH 2013 pulp thus rendered deficient in alkali and enriched in organic material should therefore be removed and replaced by small amounts of fresh alkali in order to obtain well-cooked pulps, light in colour and lower pentosen content.

Bleaching

Pulp bleaching is a process whereby wood pulp is whitened by sequential bleaching and extraction. Under acid or alkaline conditions, chlorine dioxide reacts oxidative with colour causing organic compounds, degrading them and increasing the brightness of the pulp. Alkaline stages, with or without chemicals such as oxygen and hydrogen peroxide, are used between the acidic oxidizing stages to solubilise and remove the reacted material from the pulp. Bleach filtrate from each step of pulp bleaching are usually analysed to identifying organic compounds that are toxic or that could cause oxygen depletion and dissolved solids causes surface scale in land.

Alkaline pH bleaching

During bleaching process, light scattering is retained and light absorption is reduced. The illusion of whiteness in bleaching is created by eliminating light absorption from pulp by the reduction of Chromophore group present in the fiber. Chlorine dioxide is commonly used as bleaching agent today in majority of pulp mills throughout the world (10 & 11). It is a general practice to maintain the pulp pH at 2-2.5 in the D_{HT} stage (12) and it is maintained by the addition of Sulphuric acid. However, addition of Sulphuric acid has negative effects on environment and pipe line scale properties for example increasing calcium Sulphate scale. The solubility of calcium Sulphate scale is a temperature dependent. The solubility of calcium Sulphate scale in water decreases with increase temperature. In other words, Calcium Sulphate scale is soluble in cold water but almost completely insoluble in super-heated water. Consequently, Calcium Sulphate gets precipitated and form hard scale on the surfaces of the pipe lines. Acid stage bleach plant effluent, which is let out from the pulp mill, will also have high TDS, Sulphate and temperature and needs special attention during downstream effluent treatment. At Higher pH, higher molecular weight lignin fragments soluble in alkali, at base concentrations of 0.5- 1% and pH ~ 12, but some portion is insoluble even at severe alkaline conditions. The alkaline environment also decreases lignin's hydrodynamic volume, allowing greater diffusion from the cell wall (13, 14 and 15). Several sodium hydroxide reactions with lignin increase the solubility of the lignin.

Freshly prepared solutions of Chlorine dioxide solution and other bleaching and extracting chemicals Sodium Hydroxide and hydrogen peroxide were prepared in the lab. Water and bleaching or extracting chemicals were added to 250 g of oven dried pulp in polyethylene bags. The bags were kneaded by hand and placed in a temperature controlled water bath. After each of the bleaching stages, pulp was filtered to collect the spent bleaching liquor. The pH of the spent liquors was measured, and the liquors stored in plastic containers. Between bleaching stages, the pulp was washed with clean water, which was filtered from the pulp and discarded. The brightness of a sub sample of bleached pulp was measured according to the standard TAPPI Test Method (T 452) to ensure that Laboratory scale bleaching produced pulps at a final brightness of 87% ISO.

Unbleached EH2013 pulps were prepared from laboratory cooking process was used without Oxygen Delignification. The two pulps were bleached in the laboratory to achieve a target brightness of % ISO according to the following stage bleaching sequence: **D₀EpD₁**. The use of chlorine dioxide at lower and higher pH in the first stage has been studied EH2013 pulp, and typical application and its impact on effluent generation are discussed elsewhere.

The following (DoEpD₁) bleaching sequences were carried out for EH2013 wood pulps:

D₀ Stage

Screened EH2013 pulps of 10% consistency without ODL stage were used and their pH was adjusted to Acidic and Alkaline stage for ClO₂ bleaching experiments. Then freshly collected ClO₂ was added into the polythene bags and the pulp was mixed well and noted its pH and put the pulp contained polythene bags in a preheated water bath at 75⁰C for 90 minutes with intermittent mixing of the pulps. After noted the end pH of the pulps and the pulps were filtered, washed with hot water followed by DM water and thickened the pulps for preparing second bleaching stage. Kappa number and optical properties of the washed pulps were determined. The D₀ bleaching conditions, physical and optical properties were as in table: II&III.

Ep Stage

The pulps from the D₀ stage were adjusted to 10% consistency with DM water and NaOH addition was chosen to yield a terminal pH of 10.2-10.5. After noted the pH, 1.0 % Hydrogen peroxide was added and noted

the pulp mixture pH. Then (Ep) bleaching stage was performed in a preheated water bath at 75°C for 90 min. At the end of the (Ep) stage, the pulps pH were noted and filtered. The filtrates were collected, and the pulp was thoroughly washed with hot water followed by DM water and thickened pulp for final chlorine dioxide (D₁) bleaching stage. The Ep bleaching conditions, physical and Optical properties were as in table: II&III.

D₁ stage

The pulps from the Ep stage were adjusted to 10% consistency with DM water and 0.8% chlorine dioxide charge was chosen to all pulps to achieve a target Brightness (87.0 %ISO). After noted the pulps pH, (D₁) stage was performed in a preheated water bath at 75°C for 120 min. After noted the pulps end pH, the pulps were filtered and the filtrates were collected, and the pulp was thoroughly washed with hot water followed by DM water. The thickened pulps were stored in polythene bags for determination of its strength and optical properties. The D₁ bleaching conditions, physical and optical properties were as in table: IV&V.

Pulp characterization: At all stages brightness, kappa number and strength properties of the pulps were carried out as per TAPPI standard methods. Pulp brightness was measured with an optical Spectrometer by using white tiles as standard. For calculating tear, tensile and burst indices, the hand sheets were made as per ISO DP 5269 and dried on plates in standard conditions and conditioned at 27±1°C and 65±5% relative humidity and tested according to TAPPI standards. Hand sheet properties are reported on an oven dry basis. The unbleached and bleached pulp properties of EH2012 were shown in table: IV & V.

Fiber analysis: The determination of average pulp fiber geometrics was a tedious work involving microscopy until the 1980. Equipment for these determinations, based on a flow of a much diluted pulp suspension through a cell, the recording of pictures of the pulp constituents by 2D CCD camera and picture analysis software, was then developed. In this work Fiber Lab, Metso Automation has been used to determine pulp fiber properties: The Fiber Lab analyser automatically measures classifies and reports on the dimensional properties of fiber samples. Approximately 20 000 fibers were measured in each sample, and the mean fiber length, fiber width, fines, cell wall thickness and shape factor (curl) are examples of properties that can be measured or calculated. The measured values are tabulated in Table VI & VII [Metso Automation. - FiberLab™, Research-quality fibre measurement for mill process management, Leaflet, 2001.]

Effluent analysis: Low carry over to bleaching and a low carryover amount of filtrate in each bleach stage is very important. At all stages, the filtrate were collected and tested as per standard testing methods. Effluent characteristics like Colour, Total Dissolved solids (TDS) inorganic and Chemical Oxygen Demand (COD) were measured and the tested values listed in table: VIII & IX.

III. Results And Discussion

The oxidized lignin compounds remains in the pulp fiber after the D₀ stage, and can only be removed by a subsequent alkaline extraction stage. As expected, the charge of sodium hydroxide necessary to extract the oxidized, water-soluble material quantitatively is related to the kappa number of the pulp entering the D₀ stage. The pH profile has a major effect in determining the efficiency of chlorine dioxide bleaching. The screened pulp thus rendered deficient in alkali and enriched in organic material should therefore be removed and replaced by small amounts of fresh alkali in order to obtain well-cooked pulps, light in colour and lower pentosen content. During acidic or alkaline pH bleaching, the pH is decreased considerably during the first reaction phase due to the formation of organic and hydrochloric acids. Hence, sodium hydroxide must be added to maintain the optimal end pH in the range between 6.0 and 5.9 (D₀). According to Reeve and Rapson, approximately 0.6 kg NaOH should be added for each kg ClO₂ charged to the air dried ton of pulp to ensure an optimal end pH but in this alkaline pH D₀ stage followed by extraction stage has consumed 0.45 kg NaOH instead of 0.9kg consumed by acidic pH D₀ stage.

The chemistry of bleaching might not be as obscure as some of the earlier reviews have indicated; the complexity of the partial reactions makes it extremely difficult to understand the overall effect. Obviously there is need for a full computational simulation package that can bind together the kinetics and equilibria of chemical reactions and mass transfer (Kuitunen et al. 2005).

Although the chlorine dioxide speciation into chlorite, chlorate, chloride and organically bound chlorine, etc. is quite well investigated for "normal (60-70°C)" chlorine dioxide delignification/bleaching and brightening (Chang et al. 2001; Ni 1992; Rapson, Strumila 1979; Strumila, Rapson 1976).

Reducing the bleaching chemical consumption, yet reaching the target brightness has important cost and environmental consequences. Bleach chemical consumption at the first stage is a function of pulp kappa number; the extracted kappa number that decides the bleach chemical consumption in the following stages depends on first-stage delignification. The changes made in pulping could influence the bleaching response of

pulps. Therefore, it is important to determine whether the use of digester additives or oxygen delignification stage would impact the bleachability of pulps. But high kappa bleaching of EH2013 shows better delignification and brightness development in initial chlorine dioxide, which enhances the bleachability of extraction followed by final chlorine dioxide stage to get the required brightness.

It has been reported that southern hardwood kraft pulps with high initial kappa number have lower resistance to oxygen delignification and a higher reaction rate compared to pulps with low initial kappa number (Hart et al. 2011). The reason for this observation is that the kappa number represents a combination of different oxidizable components: lignin, nonlignin oxidizable structures, and hexenuronic acids (HexA), and the relative contribution of HexA, which are resistant to Oxygen and Hydrogen peroxide treatment (Tenkanen et al. 1999, Ragnar 2001). In this study of EH2013 wood pulp shows the trend of consume slightly excess chlorine dioxide at higher kappa without ODL.

Results indicative in Table: II & III, no marginal change in bleaching efficiency was noticed between acidic and alkaline pH delignification of the EH2013 pulps. In spite of the fact that same (1.80%) ClO₂ was consumed in both experiments; the kappa number after extraction was more or less identical. Previous works have shown that Lignin reduces ClO₂ to Chlorous acid or Chlorite ion depends on pH and hypochlorous acid in parallel reaction. In the present case, EH2013 pulp delignification efficiency in the D₀ stage, expressed as kappa number reduction was 63.6 & 65.5% for the Acidic D₀ stage, as compared with 65.3% & 64.9% for the alkaline pH initial ClO₂ bleached EH2013 Pulp.

In the case of the acidic or alkaline pH pulps, as shown in Table: II & III, there was no Brightness variation with respect to delignification efficiency, which is sensitive to operating conditions and perhaps also to unbleached pulp characteristics. In this regard, it is worth noting that alkaline pH bleaching method was made an attempt to optimize the ClO₂ addition, for bleaching performance of EH2013 pulp and its filtrate properties are better than acidic filtrate for the environmental concern.

It is apparent that there is no difference in D₀ (Ep) delignification efficiency between acidic and alkaline pH bleached pulps, or between the two kappa numbers investigated in this study and also in the observation found in previous study (8). This extraction stage kappa reduction (47.0 & 50.0%) in acidic pH and (47.7 & 49.2%) in alkaline pH D₀ stages suggests that the relative bleaching of EH2013 pulps has ease of lignin removal of both unbleached kappa numbers.

The bleaching stage, chemical consumption was same during the acidic D₀ bleaching when compared to alkaline bleaching except sodium hydroxide and sulphuric acid consumption. The maximum chemical saving in alkaline pH initial chlorine dioxide bleaching was contributed by sodium hydroxide followed by sulphuric acid. This optimum temperature used in this bleaching has resulted in lower temperature of filtrate to be discharging without any cooling. The total saving in terms of chemicals and temperature reduction in initial chlorine dioxide bleaching is found to be encouraging to commercialise the alkaline pH ClO₂ bleaching in wood pulp.

The strength properties like tensile, tear and burst indices are given in table: II. The alkaline pH chlorine dioxide bleached EH2013 pulp shows 4.8 & 4.5% Tensile, 6.1 & 7.3% Tear and 9.4 & 8.4% Burst Index higher than Acidic pH bleaching of 16 & 17% TAA cooked pulp. This shows that the bleachability of EH2012 pulp at alkaline pH bleaching has shown variation than acidic pH bleaching. The target brightness can be achieved easily, if the first treatment is done effectively by proper washing of reaction products and extracting alkali soluble compounds in a subsequent extraction stage and followed by second stage (D₁) chlorine dioxide bleaching with increment in strength properties.

Influence of fiber morphology

Lignin derivatives can affect the physical properties of a paper, but other factors are important as well. Morphological factors, such as fiber length, width and coarseness and the flexibility of the fiber wall have large influence on pulp and paper properties. These parameters are to a large extent determined by the pulping raw material used. Pulps from different pulping raw materials and processes were compared, and differences in properties were also observed.

Pulps from Unbleached, acidic and Alkaline pH processes were tested, and their main wood characteristics, except the fiber width, the fines and Curl index of Alkaline pH bleached pulp were lower than Acidic pH pulp. Short and thin-walled wood fibers with low coarseness give pulp with a high number of fibers per unit mass. Pulp that contains a high number of fibers per unit weight has excellent light-scattering property. Stiff, uncollapsed fibers give high bulk to paper. Short length of fibers is the better formation. Short fibers tend to have low surface strength. High hemicellulose content and low cell wall thickness guarantee a good bonding ability for the pulp.

Information on the mechanisms of delignification at alkaline & acidic pH, and potential environmental effects was obtained by collecting and analysing filtrates from each of the bleaching stages. The resulting data are presented in Table: VIII & IX, the result shows that D₀ stage filtrate contains lower Colour (14.6 & 15.4%),

Total Dissolved Solids (10.7 & 17.9%) and COD (14.2 & 18.0%), TDS inorganic, sulphate and chlorides (chart VII&VIII) than acidic pH stage. These filtrate characteristics clearly indicates that higher pH Chlorine dioxide bleach filtrate have low Colour, TDS, and COD than the Acidic pH filtrate. High sulphate and low pH are the major contributors to filaments bulking, forming which affects the sludge settling leading to higher suspended solids carryover in secondary clarifier and performance of biological treatment (16, 17, and 18). The lower TDS inorganic in washing filtrate with lower temperature is a major environmental benefit, because there is no commercially viable technology available to reduce TDS inorganic for large scale integrated pulp and paper mills.

IV. Figures And Tables

Table: I. Unbleached pulp Cloned Eucalyptus Hybrid 2013 Properties

S.No.	Particular	16%TAA	17%TAA
1	Screened pulp yield ,%	51.35	51.20
2	Reject, %	0.28	0.12
3	Kappa number	18.9	17.8
4	Pulp brightness, %ISO	32.3	32.4

Table: II. EH2013 Wood bleaching conditions

S.No.	Parameters	16 % Acidic Condition			16 % Alkaline Condition		
		Do	Ep	D ₁	Do	Ep	D ₁
1	Initial pH	8.2	3.5	7.1	8.2	4.2	8.2
2	Acid /alkali addition,%	1.00	0.90	0.00	0.20	0.45	0.00
3	pH	3.3	11.4	7.1	10.9	11.4	8.2
4	ClO ₂ /H ₂ O ₂ addition,%	1.80	1.00	0.80	1.80	1.00	0.80
5	pH	2.2	10.2	3.7	5.8	10.5	5.6
6	Brightness, %ISO	51.4	68.8	83.4	53.6	72.9	85.7
7	Kappa number	5.8	3.6	1.4	5.5	3.4	1.3
8	Kappa reduction ,%	69.3	37.9	61.1	70.9	38.2	61.8

Chart: I, 16% TAA EH2013 Acidic pH bleaching

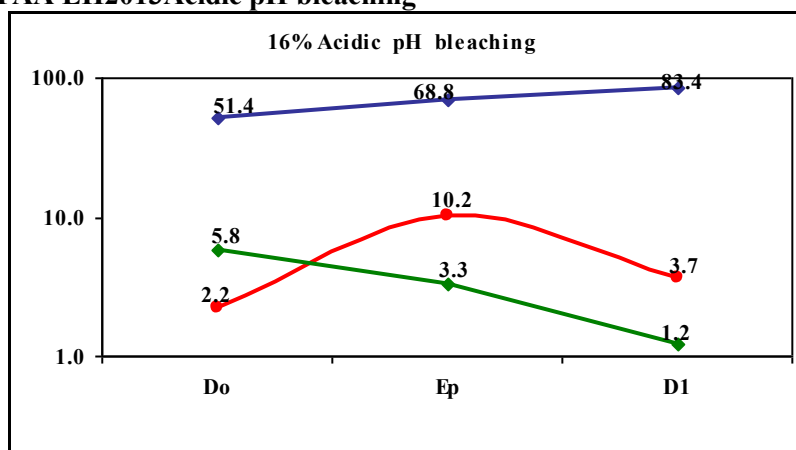


Chart: II, 16% TAA EH2013 Alkaline pH bleaching

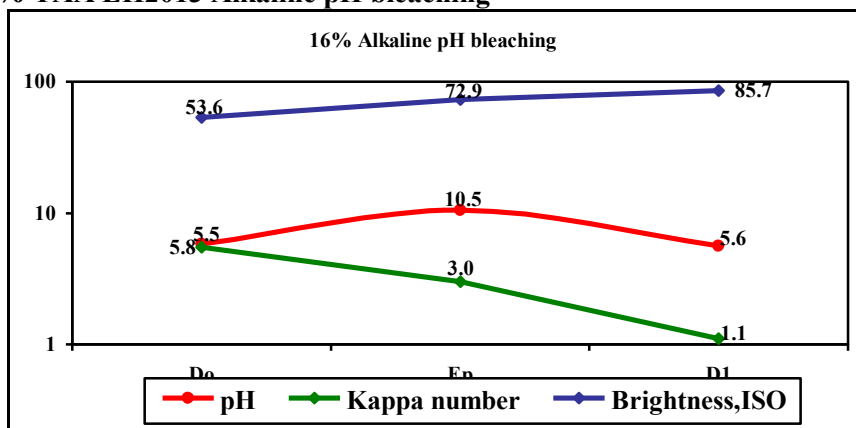


Table: III. DoEpD₁Sequence– EH2013 Wood bleaching condition

S.No.	Parameters	17% Acidic Bleaching condition			17% Alkaline Bleaching condition		
		D ₀	Ep	D ₁	D ₀	Ep	D ₁
1	Initial pH	8.2	3.8	7.5	8.2	4.2	8.2
2	Acid /Alkali addition,%	1.00	0.90	0.00	0.20	0.45	0.00
3	pH	3.7	11.0	7.5	10.8	11.2	8.2
4	ClO ₂ /H ₂ O ₂ addition,%	1.80	1.00	0.80	1.80	1.00	0.80
5	pH	2.2	10.2	5.0	4.9	10.4	5.9
6	Brightness, %ISO	53.6	68.2	84.4	55.3	70.9	86.5
7	Kappa number	5.5	3.4	1.3	5.3	3.2	1.3
8	Kappa reduction ,%	69.1	38.2	61.8	70.2	39.6	59.4

Chart: III, 17% TAA EH2013 Acidic pH bleaching

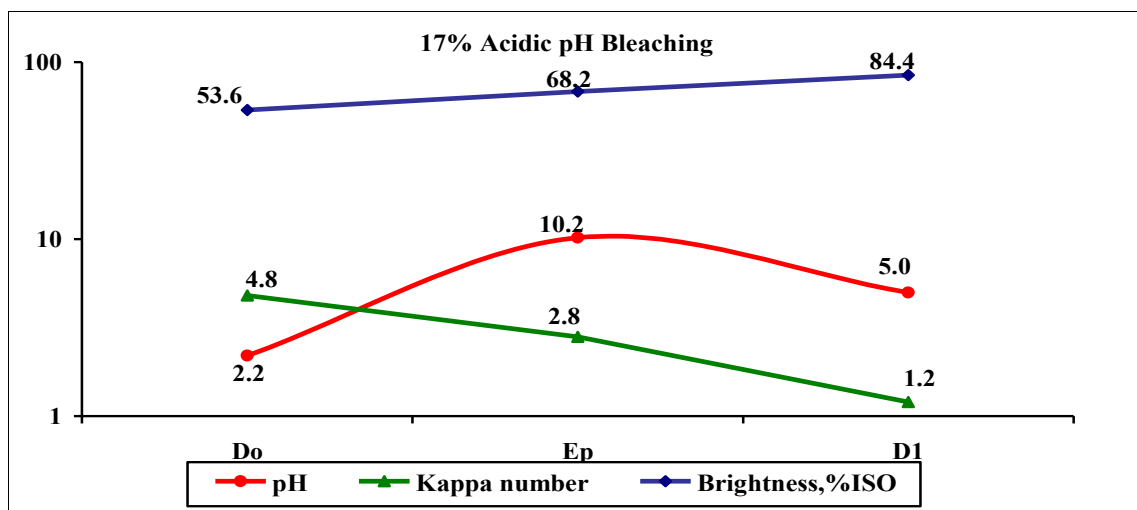


Chart: IV, 17% TAA EH2013 Alkaline pH bleaching

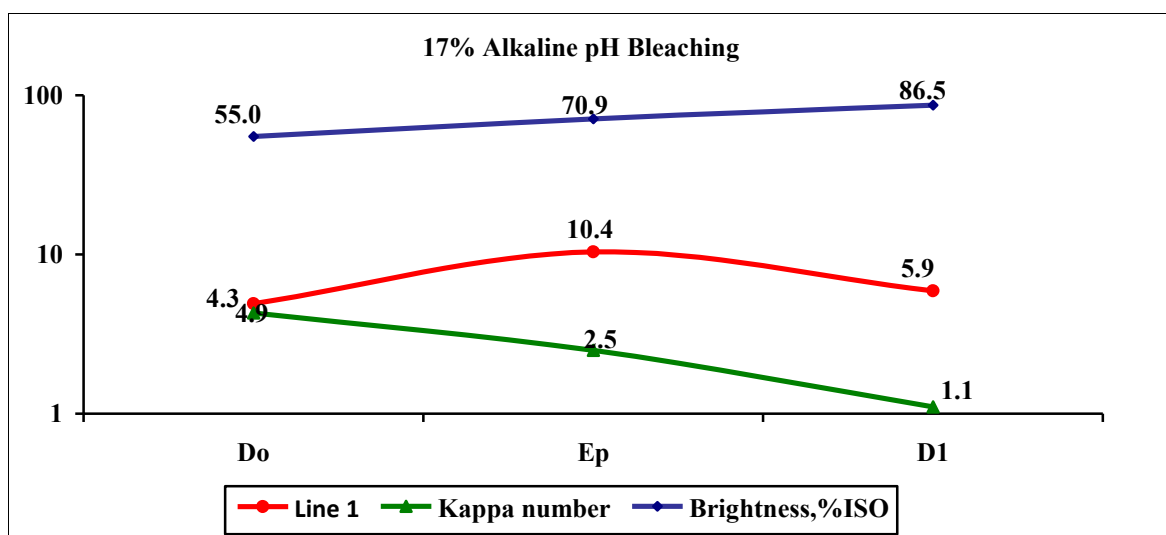


Table: IV. Strength properties of 16 % TAA unbleached and bleached pulp- EH2013

S. No.	Parameters	unit	16 % TAA Cooked Pulp		
			Unbleached	Acidic bleached	Alkaline bleached
1	CSF	ml	500	470	460
2	Bulk	cc g ⁻¹	2.08	1.92	1.88
3	Tensile Index	N m g ⁻¹	49.8	43.2	46.1
4	Tear Index	MN m ² g ⁻¹	6.5	6.94	7.18
5	Burst Index	K pa m ² g ⁻¹	2.39	2.53	2.64

Chart: V, 16 % TAA Cooked EH 2013 Unbleached & bleached Pulp strength properties

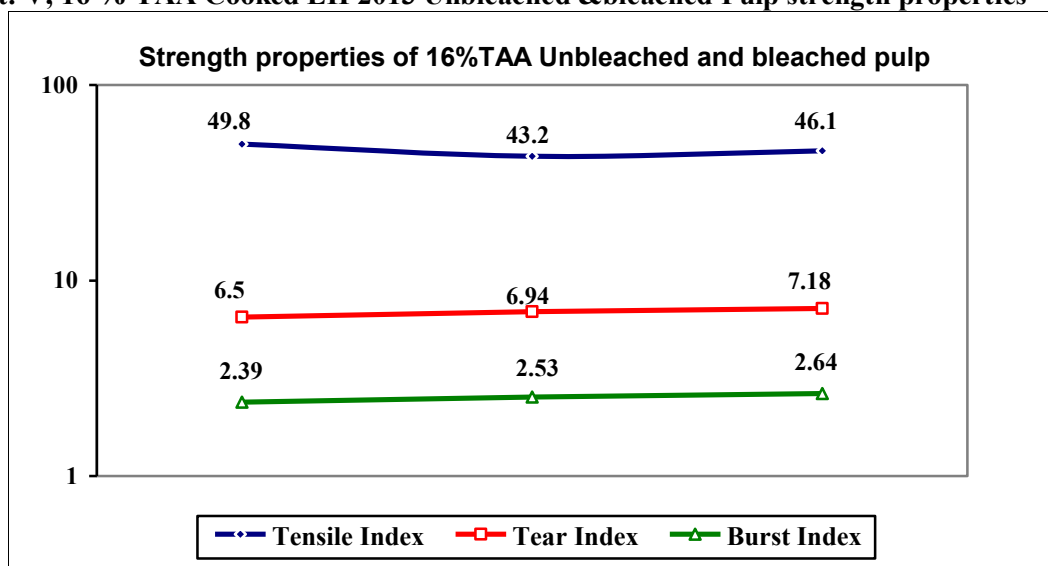


Table: V. 17% TAA Cooked EH 2013 Unbleached & bleached Pulp strength properties

S. No.	Parameters	unit	17 % TAA Cooked Pulp		
			Unbleached	Acidic bleached	Alkaline bleached
1	CSF	ml	480	470	460
2	Bulk	cc g ⁻¹	2.08	1.96	1.90
3	Tensile Index	N m g ⁻¹	49.0	43.0	44.6
4	Tear Index	M N m ² g ⁻¹	6.4	6.5	7.1
5	Burst Index	K pa m ² g ⁻¹	2.65	2.42	2.47

Chart: VI, 17 % TAA Unbleached & bleached Pulp strength properties

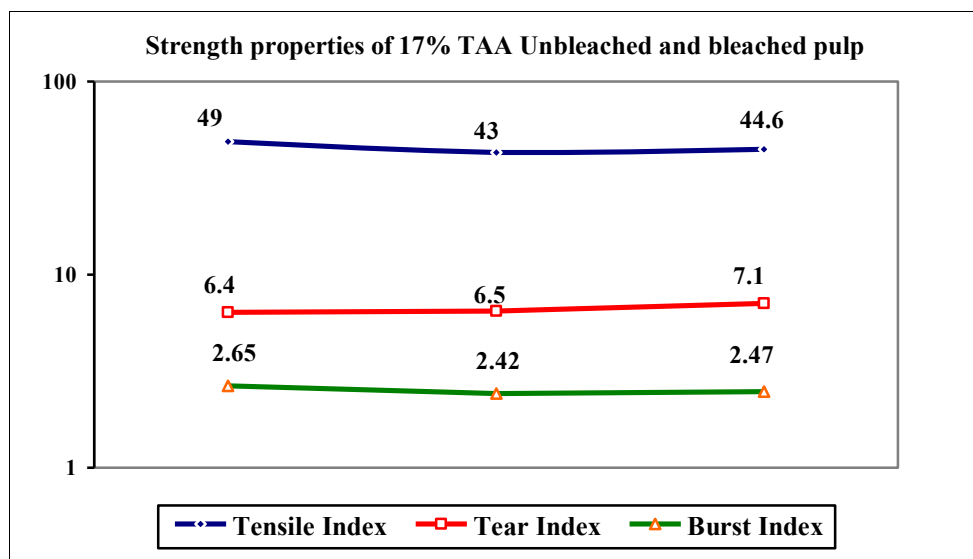


Table: VI. Fiber Morphology of 16% TAA Unbleached and Bleached pulp

EH2013, 16% TAA	Fiber length, mm	Fiber width, μm	Fine, %	Curly, %
Unbleached	0.77	14.44	8.57	11.3
Acidic pH bleached	0.74	14.08	9.36	11.9
Alkaline pH bleached	0.74	14.14	9.36	11.6

Table: VII. Fiber Morphology of 17% TAA Unbleached and Bleached pulp

EH2013, 17% TAA	Fiber length, mm	Fiber with, μ m	Fine, %	Curl, %
Unbleached	0.77	14.59	8.46	11.5
Acidic pH bleached	0.74	14.18	9.06	12.3
Alkaline pH bleached	0.74	14.25	8.96	11.5

Table: VIII. Effluent Characteristics of bleaching filtrate – EH2013

S.No	Parameters	Unit	16% TAA Acidic filtrate			16% TAA Alkaline Filtrate		
			D ₀	Ep	D ₁	D ₀	Ep	D ₁
1	Colour	Pt. Co.,	1475	1340	480	1360	1250	450
2	Total dissolved solids	mg/l	3788	3420	1896	3346	2894	1602
3	Suspended solids	mg/l	534	382	196	422	302	168
4	TDS Inorganic	mg/l	2676	2482	1410	2234	2066	1184
5	TDS Inorganic	%	70.6	72.6	74.4	66.8	71.4	73.9
6	Total COD	mg/l	1707	1816	955	1390	1462	929
7	Total Hardness	mg/l	1240	1220	840	1092	1134	800
8	Calcium Hardness	mg/l	940	920	560	780	840	480
9	Magnesium Hardness	mg/l	300	300	280	312	294	320
10	Chlorides as Cl	mg/l	1400	1250	820	1270	1050	860

Chart: VII. Effluent Characteristics of 16% TAA bleaching filtrate –EH2013

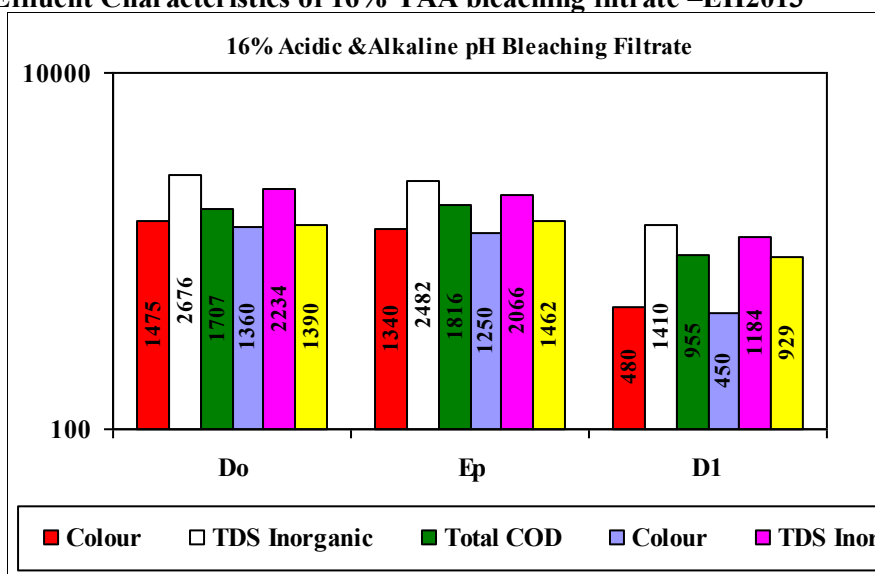
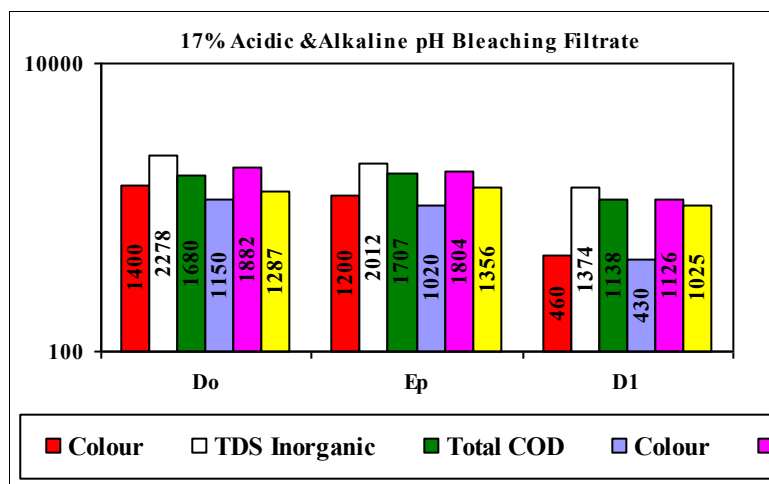


Table: IX. Effluent Characteristics of bleaching filtrate – EH2013

S.No	Parameters	Unit	17% TAA Acidic Filtrate			17% TAA Alkaline Filtrate		
			D ₀	Ep	D ₁	D ₀	Ep	D ₁
1	Colour	Pt. Co.,	1400	1200	460	1150	1020	430
2	Total dissolved solids	mg/l	3126	2852	1966	2686	2504	1580
3	Suspended solids	mg/l	472	394	272	434	342	218
4	TDS Inorganic	mg/l	2278	2012	1374	1882	1804	1126
5	TDS Inorganic	%	72.9	70.5	69.9	70.0	72.0	71.3
6	Total COD	mg/l	1680	1707	1138	1287	1356	1025
7	Total Hardness	mg/l	1480	1140	780	1244	1060	720
8	Calcium Hardness	mg/l	1140	820	470	920	750	400
9	Magnesium Hardness	mg/l	340	320	310	324	310	320
10	Chlorides as Cl	mg/l	1350	1260	750	1230	1200	760

Chart: VIII. Effluent Characteristics of 17% TAA bleaching filtrate – EH2013



V. Conclusions

The efficient and environmentally beneficial to manufacture bleached Eucalyptus pulp is achieved by terminating cook at slightly higher kappa and bleaching with the alkaline pH initial chlorine dioxide bleaching at optimum temperature with D₀EpD₁ sequence, without ODL. The investment of oxygen delignification reactor and press cost would be saved. But the oxidation efficiency of same ClO₂ consumption in EH2012 was slightly lower than the Casuarina cloned wood pulp bleaching. The strength properties of Alkaline pH bleached pulp are comparable with Acidic pH bleached pulp. The bleached filtrate characteristics were lower during the alkaline bleaching than the acid bleaching filtrate of EH2013 pulps. The maximum chemical saving is the lower sodium hydroxide consumption in alkaline pH pulp and eliminating sulphuric acid in alkaline pH bleaching sequences. Rapid alkaline pH initial ClO₂ (Do stage) bleaching of EH2013 pulp delignifies effectively and is beneficial in reducing the amount of AOX formed in the Do stage of the bleaching sequence. At high pH ClO₂ bleaching may possibly maximize extractives removal without brightness loss which decreases the deposit potential in paper machine and lesser refining energy.

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