Two-stage Alkali-Oxygen (AO) Pulping of Bagasse

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ABSTRACT

In order to evaluate the effect of alkali concentration on soaking yield and on the properties of the pulp obtained by subsequent oxygen cooking, the oxygen pressure, anthraquinone charge, cooking time, temperature and liquor to bagasse ratio were studied. It can be concluded that, the best delignification results by different alkali soaking and subsequent oxygen cooking in different NaOH concentrations are achieved at 14% NaOH for experiments which are done at 4%, 8% and 14% NaOH concentration of soaking stage, 16% NaOH in oxygen 14% NaOH concentration of soaking stage, 16% NaOH in oxygen pulping for experiments done at 6% NaOH soaking and 10% and 12% NaOH for experiments done at the same alkali charge of soaking stage. It can be also concluded that, the two-stage alkali-oxygen pulping of bagasse gave higher pulp yield at the same kappa number and R10 value, than single-stage alkali-oxygen pulping of bagasse under the same cooking conditions. Generally, this study shows that the impregnation stage before alkali-oxygen cooking of bagasse is represented as a successful process, giving higher screened pulp yield, (4-11%), higher alkali resistance and lower kappa number compared to single stage of alkali oxygen pulping of bagasse.

INTRODUCTION

Environmental problems and the high investment costs for pulp mills have led to the development of new pulping processes. The aim is to develop a process that can produce high strength pulps with good yields from all lignocellulose-containing raw materials that are suited to fibre production. The lignin content of these pulps must be low and the residual lignin must be highly reactive to permit easy, high brightness bleaching. An important criterion is also the bleachability with chlorine-free chemicals. This makes possible the treatment of the bleach effluent together with the cooking waste liquor in the recovery stage and reduces the fresh water demand of a pulp mill to a minimum. Other aims are to reduce the cost of pulp production by reducing investment costs, e.g. in the fields of chemical recovery and utilization of useful byproducts from the dissolved wood components present in the black liquor. Apart from these new developments, older ones are being reinvestigated to use if the results can be used to fulfill the current demand of pulping. From this point of view, alkali-oxygen pulping is investigated from time to time. Alkali-oxygen (AO) pulping method is considered as a sulphur-free pulping process of non-conventional pulping processes which offered the desired pulp yield and quality and which is less polluting than the conventional kraft process. There are several patents describing the pulping of wood with oxygen and alkali (1-5). The major problem of soda-oxygen pulping of wood is the difficulty of penetration of dissolved oxygen into regular size chips satisfactorily in one stage (6). The loose and open structure of rice straw and bagasse make it suitable to perform soda oxygen and soda oxygen antraquinone (SOAQ) pulping at low temperature and in shorter time in contrast to wood species. Moreover, the lignin of nonwood plants are much more sensible to the action of oxygen and anthraquinone (7).

Since the beginning of the 1980's the use of oxygen in the pulp and paper industry has been practiced, both in pulping (extended delignification) and in bleaching (alkaline extraction). This technology has succeeded in diminishing effluent pollution (8). For pulping of soda-oxygen stage, it was found that the alkali charge had a greater significance in the reaction in securing of lower kappa no. However, it had an important effect in lowering the pulp viscosity. Magnesium carbonate was used as a carbohydrate protector in both oxygen treatment for both the soda and soda anthraquinone pulps (7). Single stage alkali-oxygen pulping of bagasse has been reported with high yield but the properties of the pulps were less in strength than soda pulps (9). In the present work, a two-stage alkali oxygen pulping of bagasse by alkali impregnation followed by oxygen cooking was investigated.

EXPERIMENTAL

Material

The raw material used in this work was depithing Egyptian sugar cane bagasse. It was supplied by the pulp mill of the Egyptian Sugar and Distilling Company at

Table 1 Analytical data of depithed Egyptian bagasse

Lignin Content %	Holocellulose Content %	Hemicellulose Content %	a-Cellulose Content %	Ash %	Fibre length (mm)	Fibre width (µm)
21.74	73.53	22.75	38.86	1.311	1.95	0.35

Edfo. Depithing was carried out by the wet method at the pulp mill. The analysis of the raw material is represented in Table 1.

Pulping Experiments

Soaking Stage

In the first stage, depithed bagasse was impregnated with different concentrations of sodium hydroxide varied from 4 to 14% based on o.d. bagasse weight at room temperature for overnight using liquor to bagasse ratio 10:1, in some experiments using 20:1 as liquor ratio for comparison, then squeezing the soaked bagasse until the liquor become double the bagasse weight.

Pulping Stage

In the second stage soaked bagasse was cooked with oxygen pressure gauge at 5 kg/cm^2 in different concentrations of sodium hydroxide. All pulping experiments were carried out in an electrically heated pulping unit consisting of six stainless steel autoclaves, each having a capacity of 2.5 liter rotating in a heated ethylene glycol bath. Alkali-oxygen bagasse pulps were prepared in this work in two stages. The pulping temperature used in this experiment was 130 and 140^{0}C with time varying from 30 to 90 min. at maximum temperature. The liquor to soaked bagasse ratio was 6:1. The sealed reactor was then placed into the oil bath for the specified reaction time. Approximately 75 minutes were necessary before the contents of the reactor attained the final reaction temperature, This heat up time is not included in the stated reaction time. At the end of the cook the pulp has been washed with tap water stirred,

Table 2 Effect of NaOH concentrations on the soaking yield and on the properties of the pulping obtained by subsequent alkali oxygen cooking

Cook No.	Conc. NaOH (%)	Total yield (%)	Conc. NaOH in Cook (%)	Rejects (%)	Screened yield (%)	Kappa No.	R_{10}	Y/L
1		96.2	8	7.8	56.5	20.3	81.4	2.8
2		96.3	10	5.6	54.6	18.4	83.6	3.0
3	4.0	96.7	12	4.3	53.4	13.3	85.7	4.0
4		97.5	14	0.9	54.7	9.8	85.9	5.6
5		97.2	16	0.2	52.3	10.6	81.2	4.9
6		95.6	8	0.6	58.2	17.7	83.2	3.3
7		95.7	10	0.5	57.3	16.2	83.4	3.6
8	6.0	96.1	12	0.3	54.9	13.4	86.2	4.1
9		94.9	14	0.15	53.4	11.8	87.7	4.5
10		95.7	16	0.0	50.9	9.5	89.4	5.4
11		96.9	8	1.2	53.2	16.2	84.9	3.3
12		90.9	10	0.9	52.2	14.7	82.4	3.6
13	8.0	92.7	12	0.5	54.3	12.7	83.6	4.3
14		91.2	14	0.2	53.4	10.7	84.4	5.0
15		93.2	16	0.0	51.3	11.7	85.4	4.4
16	10.0	92.9	10	0.0	51.4	10.2	84.9	5.1
17	12.0	91.3	12	0.0	54.2	7.4	84.8	7.3
18	14.0	91.9	14	0.0	51.5	9.0	84.4	5.7
19	Single-stage SAQ oxygen pulp*		14	0.0	52.5	19.7	81.2	2.7

I Prepared by 16% NaOH, 0.1% AQ at 5 kg/cm^2 oxygen pressure for 1hr at 140^{0}C screened to remove the unreacted parts of bagasse (rejects), then centrifugated for 3 minutes in order to keep certain amount of humidity inside the fibres, weighed and then kept in a refrigerator in plastic bags. The dry weight of the solid residue is expressed as pulp yield.

Analysis of Pulp

The ash, a-cellulose, pentosans, lignin and kappa number were determined according to the Tappi Standards. The holocellulose was determined according to Method No. 28, 1951, the Institute of Paper Chemistry, U.S.A. The alkali-resistance of pulp (R_{10}) was determined according to APPCE Standard IV/39/67. The relative viscosity of pulps and was retention value (WRV).

RESULTS AND DISCUSSION

Effect of alkali concentration in the soaking on the pulp properties obtained by subsequent oxygen cooking

From Table 2 it can be noticed that, increasing the concentration of NaOH solution during soaking stage from 4% to 14%, is accompanied by a noticeable decrease in soaking yield % from 97.5% to 91%. The decrease in soaking yield % by increasing the percentage of NaOH solution during soaking stage may be attributed to hydrolysis of the hemicellulose by action of NaOH which softens the fibre wall and causes swelling of the hemicellulose and amorphous region of the fibre (12). Sugar cane bagasse belongs to grass family and has an open and less developed structure as compared to woods. It is expected that problems such as penetration of oxygen into chips and nonuniformity arising due to that will be minimum with bagasse and milder than woods. The amount of alkali and its concentration during the oxygen pulping, both have significant effects as shown from the results mentioned in Table 2 from the first set (exp. 1-5). In this Table it is obvious that increasing the amount of alkali during oxygen cooking stage from 8% to 14% causes increased loss in both kappa number and screened pulp yield by 10 and 2 units respectively. However, the alkali resistance and pulping selectivity are positively affected by increasing the alkali concentration. Further increase in alkali concentration of NaOH solution in this set results in quick loss in both yield and alkali resistance and at the same time it retards the delignification process to reach kappa number 10.6 (exp. 5). Also, the amount of rejects diminish from 7.8 to 0.2 (exp. 1,6). It can be also observed that a concentration of 14% NaOH (based on soaked bagasse) appears to give the maximum fall in kappa number in this series (exp. 4). In the second set of experiments which are done at 6% NaOH of soaking stage, varying the concentration of NaOH solution in oxygen cooking stage from 8 to 16% causes a reduction in the screened pulp yield % and kappa number by 7

Table 3 Effect of cooking temperature on two-stage alkali oxygen pulp properties

Exp. No.	NaOH in Soak : Cook	Cooking Temp. °C	Yilded (%) Cook (%) Rejects	Screen	Kappa No. (%)	R_{10}	Y : L
20	4:14	130	2.5	57.8	17.3	86.7	3.3
4	4:14	140	0.9	54.7	9.8	85.9	5.6
21	6:16	130	2.3	54.7	14.4	90.7	3.8
10	6:16	140	0.15	50.9	9.5	89.4	5.4
22	8:14	130	1.5	54.5	13.3	85.4	4.1
14	8:14	140	0.2	53.4	10.7	84.4	5.0
23	10:10	130	0.5	53.8	12.9	85.2	4.2
16	10:10	140	0.0	51.4	10.2	84.9	5.1
24	12:12	130	0.2	56.4	12.5	85.9	4.5
17	12:!2	140	0.0	54.2	7.4	84.8	7.3
25	14:!4	130	0.4	53.7	13.6	86.4	3.9
18	14:14	140	0.0	51.5	9.0	84.4	5.7

Cooking time = 60 min

At liquor ratio 10:1 in soaking stage and 7:1 in cooking stage

Oxygen pressure = 5 kg/cm² and 0.1% AQ

Table 4 Two-stage alkali oxygen pulping of bagasse at different alkali concentration and cooking times.

Exp. No.	Cooking conditions	Cooking time min	Reject	Screened Yield %	Kappa No.	R_{10}	Y/L
26		30	3.3	57.4	13.7	87.7	4.2
4	4:14	60	0.9	54.7	9.8	85.9	5.6
27		90	0.2	53.5	14.5	81.3	3.7
28		30	2.4	54.3	12.8	90.7	4.2
10	6:16	60	0.2	50.9	9.5	89.4	5.4
29		90	0.0	54.4	13.4	84.7	4.1
30		30	1.8	55.6	12.5	86.3	4.4
14	8:14	60	0.2	53.4	10.7	84.4	5.0
31		90	0.0	54.8	11.2	83.3	4.9
32		30	0.9	53.9	11.7	85.6	4.6
16	10:10	60	0.0	51.4	10.2	84.9	5.1
33		90	0.0	33.7	10.9	81.2	4.9
34		30	0.5	55.4	10.7	85	5.1
17	12:12	60	0.0	54.2	704	84.8	7.3
35		90	0.0	54.9	8.9	81.6	6.1
36		30	0.2	54.2	10.4	85.4	5.2
18	14:14	60	0.0	51.5	9.0	84.4	5.7
37		90	0.0	52.3	9.9	80.3	5.3

At liquor ratio 10:1 in soaking stage and 6:1 in cooking stage
Oxygen pressure equal = 5 kg/cm^2 and 0.1% AQ and temperature 140^{0}C

and 8 units respectively (exp. 6-10). However, the alkali resistance values and pulping selectivity are positively affected by increasing the alkali concentration. It can be said that the best delignification in this series is achieved at 16% NaOH which gave the maximum fall in kappa number (exp. 10). Also, the best delignification value in the next series (exp. 11-15) in this Table and which are done at 8% $NaOH_2$ soaking, is achieved at 14% NaOH, in the cooking stage where, the most favourable yield to kappa number relationship is observed at this ratio (exp. 14). It can be also noticed from the next set of experiments done at 10, 12 and 14% NaOH charge in both alkali soaking stage and in oxygen cooking stage that the best delignification values for these series are achieved at 12% NaOH charge in both soaking and cooking with oxygen pressure, where, the kappa number attains the least value (exp. 17).

From all these results, it can be concluded that, the best delignification results by different alkali soaking and subsequent oxygen cooking in different NaOH concentration are achieved at each of the following 14% NaOH for experiments which are done at 4%, 8% and 14% NaOH concentration of soaking stage, 16% NaOH in oxygen pulping for experiments done at 6% NaOH soaking and 10% and 12% NaOH for experiments done at the same alkali charge of soaking stage. Compared to single-stage alkali-oxygen pulping of bagasse under the same cooking conditions as shown in the same Table 2, it can be also concluded that, the two-stage alkali-oxygen pulping of bagasse gave higher pulp yield at the same kappa number and R_{10} value.

Effect of cooking temperature on pulp properties

The six different alkali-oxygen pulping conditions which are shown in Table 3 have been chosen for this study, because it gave the optimum pulping results as shown in the previous study. The pulping temperatures used in this study are 130 and 140^{0}C.

From Table 3 it can be noticed that, increasing the cooking temperature from 130 to 140^{0}C, accelerates the rate of delignification significantly in all different (AO) pulps. The kappa number is decreased by about 43% at

4% NaOH soaking, 34% at 6% NaOH, 6% at 8% NaOH, 20% at 10% NaOH, 21% at 12% NaOH and 34% at 14% alkali concentration of alkali soaking stage. Moreover, it has been observed that, increasing the cooking temperature improves the pulping selectivity of all different pulps. However, the screened pulp yields and the amount of rejects decreases by increasing the cooking temperature. The (R_{10}) values of different pulps obtained at different temperature is also, negatively affected by increasing the cooking temperature, as illustrated in Table 3

Effect of cooking time on (AO) pulp properties

From Table 4 it is clear that, increasing the cooking time from 30 to 60 minutes improves the delignification process for different pulps. The kappa number is dropped by 4 units (exp. 4), 3 units (exp. 10), 2 unit (exp. 14), 1.5 unit (exp. 16), 3 units and 1 unit for (exp. 14, 18) respectively. Extending the cooking time from 60 to 90 min. is accompanied by a pronounced increase in kappa number for different pulps, i.e., deterioration in delignification process. The increase in kappa numbers may be due to the precipitation of the lignin previously dissolved at 60 min. Therefore it can be said the best delignification, in this study is achieved at 60 min, where, the kappa number attains the least value. So, the optimum cooking time for this process was found to be 60 minutes. It has been also found that, the screened pulp yield % and the percentage of rejects decrease considerably by prolonged cooking time, especially at (4: 14% NaOH concentration) (exp. 27). Otherwise, the relatively higher yield in most different pulps is due to higher lignin residue content of the pulps, i.e., higher kappa numbers. It is also clear that, all different pulps done at cooking time more that 60 minutes, produced pulp that contained no rejects. The alkali resistance is also negatively affected by prolonged time as shown in Table 4.

Effect of liquor ratio in the soaking on the pulp properties of alkali-oxygen pulping

The effect of liquor ratio in the soaking satge on pulp properties of the (AO) bagasse pulps has been studied at different concentrations of NaOH solution in both soaking and cooking stages. The liquor ratio in soaking stage used in this study was 10 : 1 and 20 : 1. From Table 5 it was found that, the change in the liquor ratio of the soaking from 10 times to 20 times of bagasse at different concentrations of NaOH solution is accompanied by a pronounced increase in kappa number for all different (AO) pulps, i.e. the delignification process is retarded significantly. The increase in the kappa number was ca : 40% in (exp. 38), 32% (exp. 39), 10% (exp. 40), 20% (exp. 41), 15% (exp. 42) and 19% for (exp. 43).

Moreover, the pulping selectivity of different pulps is also affected negatively as shown in Table 5. It was also found that, the screened yield % and the amount of rejects decreases by increasing the liquor ratio in the soaking stage from 10 to 20 times of bagasse. Also, the alkali resistance values of different pulps are negatively affected by changing the soaking liquor ratio as illustrated in Table 5 which means that the carbohydrates fractions are more attacked in soaking liquor ratio 20 : 1 than 10 :1 (based on bagasse). From all the above results, it can be concluded that, it is not necessary to

Table 5 Effect of liqour ratio in soaking stage on the pulp properties of two-stage alkali oxygen pulping of bagasse

Exp. No.	Alkali Soaking Concn (%)	Liqour ratio	Alkali Cooking Concn (%)	Rejects	Screened Yield %	Kappa No.	R_{10}	Y/L
4	4	10	14	0.9	54.7	9.8	85.9	5.6
38	4	20	14	0.6	53.3	13.7	82.5	3.9
10	6	10	16	0.2	50.9	9.5	89.4	5.4
39	6	20	16	0.4	47.7	12.4	83.7	4.2
14	8	10	14	0.2	53.4	10.7	84.4	5.0
40	8	20	14	0.3	51.5	11.8	81.9	4.3
16	10	10	10	0.0	51.4	10.2	84.9	5.1
41	10	20	10	0.4	48.7	12.2	82.7	4.1
17	12	10	12	0.0	54.2	7.4	84.8	7.3
42	12	20	12	0.1	53.2	8.4	82.8	6.3
18	14	10	14	0.0	51.5	9.0	84.4	5.7
43	14	20	14	0.0	50.7	10.7	83.7	4.7

Table 6 Effect of $MgCO_3$ inhibitor on the pulp properties of the two-stage alkali oxygen pulping

Exp. No.	NaOH in Soaking:Cooking	Concn. of $MgCO_3$ (%)*	Rejects (%)	Screened Yield %	Kappa No.	R_{10}	Y/L
4		- -	0.9	54.7	9.8	85.9	5.6
44		0.1	0.8	56.7	10.2	86.7	5.6
45	4:14	0.5	0.6	57.5	9.7	86.9	5.9
46		1.0	0.0	58.7	8.9	87.7	6.6
14		- -	0.2	53.4	10.7	84.4	5.0
47		0.1	0.15	54.6	10.2	84.7	5.4
48	8:14	0.5	0.10	55.7	9.7	85.8	5.7
49		1.0	0.0	57.5	8.5	87.5	6.7

* Calculated on the dry weight of soaked bagasse

Table 7 Comparatively study on the Soda, Soda-AQ, Single-Stage alkali Oxygen, Two-stage alkali Oxygen AQ-Carbonate Bagasse Pulp.

Exp. No.	Pulping Methods	Yield (%)	Kappa No.	R_{10} (%)	Y/L	Relative viscosity (h)	WRV (%)	Fibre length (mm)
I	Soda	47.3	26.7	79.8	1.8	27.8	98.5	1.1
II	Soda + AQ	50.4	20.9	82.7	2.4	31.5	115	1.21
III	Single Stage ($SAQO_2$)	52.5	19.7	81.2	2.7	30.4	117.8	1.23
IV	Two-stage ($SAQO_2$)	54.7	9.8	85.9	5.6	34.3	143	1.32
V	Two*-Stage ($SAQO_2$-$MgCO_3$	58.7	8.9	87.7	6.6	35.5	195	1.37

* The same pulp condition as IV but contain 1% $MgCO_3$

increase the soaking liquor ratio in this study more than 10 : 1 (based on bagasse), to avoid the deterioration in both delignification process and carbohydrates protection.

Effect of adding $MgCO_3$ on pulp properties

From the literature, it is well known, that, the addition of magnesium carbonate as carbohydrate degradation inhibitors is necessary in maintaining the strength properties of alkali-oxygen pulp at acceptable levels, especially for unbleached grades (13). In order to evaluate the effect of adding $MgCO_3$ to the cooking liquor of alkali-oxygen anthraquinone, on the pulp properties, oxygen pressure, AQ charge, cooking time and cooking temperature were held constant at 5 kg/cm^2, 0.1%, 60 min. and 140°C respectively. Otherwise, the amount of $MgCO_3$ was varied from 0.1 to 1% on soaked bagasse, at two different concentration of alkali-soaking as shown in Table 6.

From the forementioned Table, it is clear that adding of $MgCO_3$ to the cooking liquor of the alkali-oxygen anthraquinone, has a positive effect on both the delignification process and carbohydrate protection, where, increasing the percentage of $MgCO_3$ in cooking liquor from 0.1 to 1% (based on soaked bagasse), is accompanied by a slight decrease in kappa number in two different pulps which are used in this study, from 9.8 to 8.9 and from 10.7 to 8.5 (exp. 46 and 49 respectively). However, the total screened yields and the amount of rejects are improved by increasing the amount of $MgCO_3$ in cooking liquor. The increase in the screened yield may be attributed to maximum protection of cellulose during the pulping process (14). It is obvious that, no rejects resulted at adding 1% of inhibitor $MgCO_3$ for different pulps used in this study. It has been also found that, the alkali resistance and pulping selectivity of different pulps are positively affected by increasing the percentage of $MgCO_3$ in cooking liquor, as shown in Table 6. Also, the increase in alkali resistance of the different pulps may be attributed to the protection of carbohydrate against degradation during pulping process.

Comparison between different pulps

Table 7 in results are given of soda, soda-AQ, single and two stage soda-oxygen-AQ and two stage soda-oxygen-AQ carbonate bagasse pulps prepared at the same pulping conditions. The relative viscosity (h), water retention value (WRV) and the fibre length have been studied for these different pulps and the results are included in the same Table for comparison.

From the results reported in Table 7, it is clear that, Two-stage soda-oxygen-AQ-carbonate pulping method offers higher pulping slectivity than other pulping methods. The kappa number of different pulps is in the order V < IV < III < II < I respectively. Moreover, the screened yield % of the different pulps is in the order, V > IV > II > II > I, respectively. However, the alkali resistance values of different pulps is in the order, V > IV > II > III > I respectively. It can be noticed that, soda-AQ bagasse pulps gives higher alkali resistance value than single-stage soda-oxygen-AQ bagasse pulp. This result may be due to degradation of the carbohydrate by action of active molecular oxygen during the delignification of the carbohydrate by action of active molecular oxygen during the delignification process (15). Regarding the degree of polymerization of cellulose different pulps prepared from bagasse using different methods, using of the xanthat pulps in sodium hydroxide solution indicated by relative viscosity (h) was taken for the comparison between the different pulps. At the same pulping conditions as shown in Table 7, the maximum relative viscosity is obtained with soda pulps (1). The increase in the relative viscosity of pulp No. V may be due to the presence of magnesium carbonate as inhibitor for carbohydrates degradation and also presence of anthraquinone which increased the viscosity (14). The effect of different pulping methods on the fibre swellability of the produced pulp is a very important property. The water retention value (WRV) is the most widely measured parameter of the fibre swellability in water. From the results of (WRV) for different pulps mentioned in Table 14, it is obvious that the maximum (WRV) is also obtained with pulping V, while the minimum WRV is obtained at soda pulping (1). The fibre length of different pulps give an indication of the degradation of fibers due to different pulping methods. It is also clear that, the value of fibre lengths do not vary much from pulping process to the other process but the pulping with soda-oxygen-AQ-magnesium carbonate gives higher fibre length than the other pulping processes.

CONCLUSION

The impregnation stage before alkali-oxygen cooking of bagasse is represented as a successful process, giving higher screened pulp yield, (4-11%), higher alkali resistance and lower kappa number compared to single stage of alkali oxygen pulping of bagasse. The delignification process seems to be accelerated by reaising the temperature of cooking stage from 130°C to 140°C, where, the pulping selectivity and the rejects are improved. Increasing the cooking time from 30 to 60 minutes, improves the pulping selectivity. Prolonged cooking time has been affected negatively on the kappa number and alkali resistance, but produced pulp without rejects. The best pulping results in this study are achieved at soaking liquor ratio 10:1 where, the pulping selectivity attains the most favourable result at this ratio. The addition of magnesium carbonate and anthraquinone to the cooking liquor of the two stage of (AQ) pulping of bagasse, improves the efficiency of cooking liquor towards the delignification process and carbohydrate protection. Soda-oxygen pulping of annual plants presents some advantages over conventional soda and sulphate processes such as superiority in delignification rate, higher yield and brightness, low cooking temperature, shorter cooking time and easy bleachability. In addition, air pollution associated with the sulphate process is totally eliminated and water pollution reduced. For this reason, soda-oxygen pulping for nonwood plants especially for straw and bagasse will play an important role in the near future.

REFERENCES

1. Harris, G.C.: U.S. Pat. No. 2, 673, 148 (1954).
2. Grangaard, D.H. : Tappi, 39, No. 5, 270 (1956).
3. Grangaard, D.H. and Saunders, G.H. : Can. Pat. No. 611, 503 (1960).
4. Grangaard, D.H. and Saunders, G.H.: Can. Pat. No. 632, 280 (1961).
5. Gaschke, M.M., River, T. and Spector, M.L. : U.S. Pat. No. 3, 274, 049 (1966).
6. Cox, L.A. and Wroster, H.E. : Tappi 54 (11), 1890 (1971).
7. Eroglu, H. : Non wood Plant Fibre Pulping Prog-Report No. 17, Tappi Press, Atlanta, 133, (1987).
8. FMC Technical Bulletin 140, Hydrogen Peroxide For Chemical Pulp Bleaching.
9. El-Ashmawy, A.E.:, Fadl, M.H.; Saleh, T.M. and et al. : Tappi J. 60 (6), 109 (1977).
10. Jayme, G. and Karl, Henz Rasentock : Das Papier ii, 77 (1957).
11. Jayme, G. : Das Papier, 12, 90 (1958).
12. Ito, I. : Proc. Intl. Mech. Pulping Conf. San Francisco, Calif., P. 185 (1975).
13. Chang, H.M.; Gratzl, J.S. and Mckean, W.T. : Paper presented at 166th Annual Meeting of the American Chemical Society Aug. (1973).
14. Trivedi, M.K. and Murthy, T.S. : IPPTA (19) 2, (1982).
15. Dutt Dharm; Upadhyaya, J.S.; Upadhyaya, M.K. and Tiwary, K.N. : IPPTA, 85 (1994).