Oxygen bleaching of kraft pulp: high consistency vs. medium consistency

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Pulp viscosity at a given degree of delignification is slightly higher for medium-consistency bleaching than for high-consistency oxygen bleaching.

Bleaching with oxygen for further delignification after the cooking is an established industrial process. Since the first commercial units were started early in the 1970s, many plants have been installed. Two major Swedish suppliers had installed and started 34 oxygen bleaching stages at the beginning of 1987.

More than 50% of the Swedish capacity of bleached kraft pulp—2.3 million metric tons/year—is today oxygen-bleached. In the near future, more than 70% of the bleached kraft pulp production in Sweden will be oxygen bleached.

In general, handling a pulp slurry at medium consistency is an advantage in screening, washing, and bleaching. Because chemical mixers for medium-consistency operation had been developed, it is not surprising that during the last 4 years most of the installations for oxygen bleaching have incorporated a medium-consistency system.

Here, we will look at the total operational costs and the reduction in water pollution associated with oxygen bleaching in an existing mill.

Mill experience

Our experience and conclusions for high-consistency oxygen bleaching are based on three installations in Sweden over a long operational period. For medium-consistency oxygen bleaching with the same type of wood raw material, experience is, however, limited. The results are therefore based mainly on our experience in one Swedish mill. Oxygen bleaching of both pine and birch kraft pulps are covered, since the mills alternate between these pulps in 2-5 day production cycles. The mills were chosen to obtain the same relationship between kappa number and viscosity for the unbleached pulp from the different mills. All these mills produce a fully bleached market pulp.

Table I gives the degree of delignification, the viscosity loss in the oxygen stage, and related chemical charges for high-consistency and medium-consistency oxygen bleaching of pine kraft pulp. Corresponding data for birch are also summarized in Table I.

Data for high-consistency oxygen bleaching should be considered as an example of normal values. Some variations do, however, occur from time to time depending on local conditions. For the medium-consistency oxygen bleaching, the values given are average values for a period of some weeks.

I. Mill data for high-consistency and medium-consistency oxygen bleaching with Swedish pine and birch pulps

	Pine		*Birch*	
	High	*Medium*	*High*	*Medium*
Unbleached pulp				
Kappa number, SCAN	32	30	20	22
Viscosity, dm^3/kg	1150	1110	1220	1270
O_2 bleached pulp				
Kappa number, SCAN	19	17	12	15
Viscosity, dm^3/kg	950	980	1050	1170
Degree of delignification, %	40	42	40	32
Viscosity loss/ kappa no., O_2	15	10	20	14
Charges in O_2 stage				
Sodium hydroxide, kg/metric ton	17	16	16-18	11
Oxygen, kg/metric ton	16	16	16-18	11
$MgSO_4$, kg/metric ton	2	7	2	7

The degree of delignification over the oxygen stage is fairly low (40%) and is about the same for pine and birch in both the high-consistency and medium-consistency oxygen stages. A higher delignification degree of 50% is used in some other mills for pine kraft pulp. The extent of delignification chosen depends on local conditions—e.g., cooking conditions and process control systems.

These mill results indicate that the selectivity is better for the medium-consistency oxygen bleaching. The difference between the high-consistency and medium-consistency oxygen processes, expressed as viscosity loss per kappa number reduction over the oxygen stage, is about 5 dm^3/kg to the advantage of the medium-consistency oxygen process. This comparison seems to be valid for both pine and birch kraft pulps.

Compared at the same extent of delignification, this gives an improvement for the medium-consistency oxygen process of the order of 60-70 dm^3/kg in viscosity for pine kraft pulp and 40-50 dm^3/kg for birch kraft pulp. The degree of delignification in oxygen bleaching of birch should, however, also be optimized as to the yield, which is a limiting factor.

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II. Basis for economic and effluent evaluation specification for kraft pulp

	Pine			Birch		
	Conven.	*High*	*Medium*	*Conven.*	*High*	*Medium*
Unbleached pulp						
Kappa number, SCAN	32	32	32	20	20	20
Viscosity, dm^3/kg	1150	1150	1150	1200	1200	1200
O_2 bleached pulp						
Kappa number, SCAN	...	18	15	...	14	12
Viscosity, dm^3/kg	...	940	940	...	1080	1080
Bleaching						
Wash. res., COD, kg/metric ton	10	10	10	10	10	10
Bleaching sequence		(C+D)(E+O)DED			(C+D)(E+O)DED	
Amount of dioxide in (C+D), active chorine, %	15	15	15	15	15	15
Pulp production, metric tons/day	600	600	600	600	600	600

III. Basis for the economic evaluation

Softwood, SEK*/metric ton of dry wood	840
Hardwood, SEK/metric ton of dry wood	590
Electricity, SEK/kW·h	0.2
Steam, SEK/ton	140
Chlorine, SEK/kg	1.25
Chlorine dioxide, SEK/kg active chlorine	2.5
Oxidized white liquor, SEK/kg NaOH	0.5
$MgSO_4$, SEK/kg	1.2
Sodium hydroxide, SEK/kg	1.4
Oxygen, SEK/kg	1.0

*Swedish Krona 1 SEK = $0.16

IV. Basis for economic evaluation: consumptions and yield in oxygen stage

	Pine		Birch	
	High	*Medium*	*High*	*Medium*
Oxygen, kg/metric ton	17	21	12	16
Oxidized white liquor, kgNaOH/metric ton	17	21	12	16
$MgSO_4$, kg/metric ton	2	1	2	1
Electricity, kW·h/metric ton	75	55	75	55
Steam, kg/metric ton	40	200	40	200
Pulp yield, %	96.9	96.2	98.2	97.6

Similar results have been reached in laboratory trials on softwood, especially when the pulp included black liquor components (*1-4*). From Zellstoff Pols AG in Austria, a viscosity loss over the medium-consistency oxygen stage of about 10-12 dm^3/kg per kappa number unit has been reported for softwood (*5*).

The improved pulp viscosity using medium-consistency oxygen bleaching could be utilized for an increased delignification corresponding to an increase of from 40% to 50% or 60% for pine and from 30% to 40% or 50% for birch. These higher degrees of delignification have also been established over short periods without detriment to bleached pulp viscosity in a mill with a medium-consistency oxygen installation. However, more operational experience is needed to evaluate the higher delignification degree and its influence especially on the pulp quality.

According to laboratory results on softwood, the consumption of oxygen and alkali is about 10% higher in a medium-consistency oxygen stage than in a high-consistency oxygen stage at the same degree of delignification (*1, 5*). Such a difference cannot be verified in the mills because of relatively high standard deviations in the charges in both high-consistency and the medium-consistency oxygen systems.

Costs and environmental effects

The installation of oxygen bleaching in an existing mill means extra capital cost. However, on the positive side, reduced bleach chemical consumption and reduced water pollution are obtained. The resulting total costs, including operational and capital costs, depend on local conditions and should be considered for each installation. The economic and effluent figures presented here are based on mill results, and the pulp specifications are given in **Table II.**

The tendency toward better selectivity for the medium-consistency oxygen system has been utilized for a possible higher degree of delignification in the oxygen stage. The washing loss into the bleach plant must be kept on a low level to avoid unnecessary water pollution. This is true for mills both with and without oxygen bleaching, and a low washing residual, given as COD with pulp, is therefore assumed. A five-stage bleaching sequence with reinforced alkali stage and with 15% chlorine dioxide in the (C+D) stage is used in the comparison.

A low total active chlorine charge, 86 kg/metric ton of bleached pulp, which means 2.7 kg/kappa number for the pine conventional case, has been assumed as a reference. Corresponding values for birch are 60 and 3.0, respectively.

V. Differences in variable operational costs in SEK/metric ton

	Pine			Birch		
	Conven.	High	Medium	Conven.	High	Medium
Kappa number, SCAN	32	32/18	32/15	20	20/14	20/12
Wash. res., COD, kg/metric ton	10	10	10	10	10	10
Wood	ref.	+8	+8	ref.	+3	+3
Electricity and steam	ref.	+21	+39	ref.	+21	+39
Chemicals	ref.	−56	−69	ref.	−40	−42
Steam from recirculated organic substance	ref.	−29	−34	ref.	−13	−21
Total	ref.	−56	−54	ref.	−29	−21

A 600-metric ton/day mill.

VI. Differences in total costs for oxygen bleaching in a kraft mill in relation to a conventional system, a 600-metric ton/day mill

	Pine		Birch	
	High	Medium	High	Medium
Investment, 10^6 SEK	70-90	40-50	70-90	40-50
Variable costs	−56	−54	−29	−21
Maintenance[a]	10-13	6-7	10-13	6-7
Capital costs[b]	44-57	25-31	44-57	25-31
Total costs	(-2)-14	(-23)-(-16)	25-41	10-13

[a]3% of the investment. [b]Depreciation 15 years and 10% interest.

Prices used for energy, wood, and chemicals are budget prices related to Swedish conditions (**Table III**). Calculated data for consumptions and yield in the oxygen stage are summarized in **Table IV**.

The higher consumption of steam in a medium-consistency oxygen process is valid only in the case of screening before the oxygen bleaching. When the medium-consistency oxygen process is installed before the screening, there will be no significant difference in steam consumption between the high-consistency and medium-consistency oxygen processes.

Oxygen bleaching of pine kraft pulp reduces the variable operational cost by 50–60 SEK/metric ton of bleached pulp compared with a system without oxygen bleaching. For birch kraft pulp, the decrease is less at about 20–30 SEK/metric ton of bleached pulp. The variable operational costs divided into wood, chemicals, and energy for high-consistency and medium-consistency oxygen systems in relation to a conventional system are given in **Table V**.

To illustrate the net effect of the production cost, the investment for installing a complete oxygen bleaching system in an existing mill is given in **Table VI**. The investment is given with a range because local variations have a considerable influence. No extra investment on the recovery side has been assumed. The extra dry solids content with the oxygen stage for pine kraft is about 60 kg/metric ton, and for birch kraft it is about 40 kg/metric ton. These amounts correspond to an increase of 4% and 3%, respectively, in the total dry solids content, and it should be possible in most cases to take these to the recovery side without any extensions.

In the reference case with a conventional system, the washing must in many mills be completed with an extra washing stage to reach the assumed washing residual of 10 kg/metric ton as COD. The investment for such a washing stage has not been taken into consideration in the calculations.

With regard to total costs (Table VI), the medium-consistency oxygen process has a cost advantage over the high-consistency oxygen. When a medium-consistency oxygen system is incorporated into a mill using pine kraft pulp, the total costs will be lower than those for the conventional system without oxygen bleaching. For a mill having a separate hardwood line, such as birch, the cost benefits are not as favorable as for pine or similar softwoods.

The introduction of oxygen bleaching means reduced water pollution. For these cases, the estimated discharges from the bleach plants are given in **Table VII**. Local conditions influence the discharges, which means that mill specific values may deviate from these.

Final bleaching

The use of oxygen bleaching makes it possible to reduce the number of final bleaching stages. With oxygen bleaching, whether high consistency or medium consistency, the bleach chemical costs for fully bleached pulp will be higher by about 10 SEK/metric ton in a three-stage final bleaching than in a five-stage sequence. On the other hand, the maintenance and energy costs are lowered by the same amount. Furthermore, the cleanliness of the pulp from a three-stage bleaching plant will be better.

In an existing mill, the pulp production can be extended for a relatively moderate investment by using oxygen bleaching and a three-stage final bleaching sequence by dividing the bleaching plant into two lines.

VII. Estimated water pollution from the bleach plant

	Pine			Birch		
	Conven.	High	Medium	Conven.	High	Medium
Kappa no., SCAN	32	32/18	32/15	20	20/14	20/12
BOD_7, kg/metric ton	14	10.5	9.5	14.5	11.5	10
COD, kg/metric ton	80	50	45	50	40	35
TOCl, kg/metric ton	5-5.5	3-3.5	2.5-3	2-2.5	1.5-2	1.5
Reduction in acute toxicity to fish, % of reference	ref.	50-60	60-70	ref.	n.a.	n.a.

n.a. = not yet evaluated. TOCl = total organic bound chlorine.

Future trends

An advantage with oxygen bleaching is that oxygen is cheap and that little electricity is needed for the production of the oxygen compared with the electricity requirement for other bleaching chemicals.

Because organic chlorinated components are harmful to organisms living in water, the restrictions on the discharge of these components will probably become stricter. A big step forward to reduce such components is the introduction of oxygen bleaching. In most cases, medium-consistency oxygen bleaching will probably be installed because the selectivity is slightly better than that of high-consistency oxygen. With pre-stages under development, such as that using nitrogen dioxide, PRENOX, the selectivity can be even better, and this improvement can be used for further delignification in the oxygen stage.

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