

Ozone-enhanced bleaching of softwood kraft pulp

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ABSTRACT: By using ozone in their bleaching processes, many hardwood pulp mills in various parts of the world have improved product quality and their environmental and process performance, and reduced operating costs to increase competitiveness. The challenge for softwood pulp is to rethink the use of ozone according to their specific requirements. This paper summarizes results obtained using ozone bleaching on softwood (*Pinus radiata*) kraft pulp, for which the brightening ability of limited ozone dosages can enhance the economic benefits without impairing pulp quality. This work evaluated the chemical justification to use ozone at the end of the bleaching sequence and the effect on pulp quality, and considered the practical consequences of this new option. Special attention was given to the economic and technical aspects, including investment cost, variable cost, and process implementation. Ozone was shown to be the ideal complement of chlorine dioxide for final pulp bleaching. Both chemicals can easily be combined at the end of the bleaching sequence. Taking into account pulp mill capacity, capital investment, and total operating cost, the financial savings were calculated to be in the range of EUR 5 million (USD 6 million) per year, with a payback period of about 1.5 years.

Application: Use of limited ozone charges after the alkaline extraction stage in softwood pulping is an innovative solution to help mills optimize pulp bleaching chemical costs.

The first fiber lines producing softwood or hardwood ozone bleached pulp are mainly associated with the emergence of totally chlorine free (TCF) bleaching during the 1990s. That decade boosted the arrival of new bleaching practices based on the use of oxygen, ozone, and peroxide. In some cases, the ozone dosage in pulp bleaching was not accurately controlled and some pulp degradation occurred. In addition, ozone generation technology for large-scale installations was new at that time and reliability and chemical availability were occasionally an issue. During that period, much discussion focused on the pros and cons of TCF, elemental chlorine free (ECF), and ozone bleaching. Some experts claimed that ozone bleaching was not ready for continuous operation, others said it would become a major chemical for pulp bleaching technology in the coming years. In 1996, when the TCF “wave” stopped, ECF bleaching (mainly based on chlorine dioxide) became the best available technology (BAT), and ozone started to be integrated into conventional ECF bleaching to significantly reduce the operating cost of the bleaching sequence [1].

Since the startup of the first ozone pulp bleaching installations in 1992 at Lenzing AG, in Lenzing, Austria, and the Union Camp mill in Franklin, VA, USA, many alterations have been made to improve all the components of the ozone bleaching systems (e.g., pulp mixing, ozone generation technology). Today, ozone bleaching is fully adapted to hardwood pulp bleaching [2]. In most cases, ozone is used to reduce the chemical cost and to improve the environmental impact. Most systems apply the ozone just after oxygen delignification to

finalize lignin removal before the final bleaching phases [3]. The ozone charge is generally in the range of 5 kg/ton of pulp. Depending on the mill's expectations and equipment supplier, the ozone stage can be supplied at high consistency (HC) or medium consistency (MC).

Most pulp mills have chosen ozone to produce hardwood pulps at high brightness levels (**Table I**). Extended ozone delignification lowers bleaching chemical costs, and allows mills to reduce the amount of effluent reject to be treated because the filtrate from the ozone (Z) stage and further alkaline extraction stage can be circulated back to the recovery boiler [3]. Ozone is frequently investigated at the initial phase of the project where hardwood bleached pulp is concerned, whether for greenfield mills, new fiber lines (capacity expansion), or retrofit options, giving the mill the opportunity to adopt an efficient light-ECF process.

For softwood pulp production, the situation is quite different. Since 1999, only three mills with combined production of hardwood and softwood pulps have chosen ozone; the most recent, in Portugal, produces ozone-bleached pulps from *Eucalyptus* and pine. In general, ozone is still considered a risky chemical for softwood pulping because of potential reduction of pulp strength. Various studies mention that ozone can affect the strength properties of softwood pulps [4,5]. The effect of ozone on these pulps is known to be linked to the ozone charge [6]. Taking into account the specific constraints of softwood pulp bleaching, a promising approach is to reduce the ozone dosage to avoid any detrimental effect on the strength properties and to move the ozone stage to the end of the bleaching sequence [7].

No.	Mill	Country	Location	Pulp Process	Pulp Type	Bleaching Sequence	Pulp Capacity (a.d. tons/day)	Ozone Process	Ozone Supplier	Startup
1	Lenzing	Austria	Lenzing	Sulfite	HW	EOP - Z - P	600	MC	Wedeco	1992
2	UPM	Finland	Pietarsaari	Kraft	HW	A-ZD-Eop-ZD-Ep	1300	MC	Wedeco	1992
3	Nordic Paper	Sweden	Säffle	Sulfite	SW	Q-Z-E-P	150	MC	Wedeco	1994
4	SCA Pulp	Sweden	Sundsvall	Kraft	SW	Q-OP-Zq-PO	1250	HC	Ozonias	1995
5	Sateri	Brazil	Bahia	Kraft	HW	A-ZQ-P	400	MC	Wedeco	1995
6	Sappi	South Africa	Ngodwana	Kraft	HW/SW	ZD-E-D	1000	HC	Ozonias	1995
7	NewPage	USA	Wisconsin Rapids	Kraft	HW	Z Eo D D	650	HC	Ozonias	1995
8	Fibria	Brazil	Jaccarei	Kraft	HW	Line B = A-Z-D-PO Line C = A-Ze-D-P	1200 2100	MC HC	Ozonias Wedeco	1995 2002
9	International Paper	Brazil	Luiz Antonio	Kraft	HW	ZD-EOP-D	1100	MC	Ozonias	1995
10	Domtar EB	Canada	Espanola, Ontario	Kraft	HW	A-ZD-Eo-DnD	800	MC	Ozonias	1998
11	Rosenthal	Germany	Blankenstein	Kraft	SW	Q OP Z POP=TCF Q OP D Z POP=ECF	900	HC	Wedeco	1999
12	Burgo	Belgium	Ardenne	Kraft	HW	D-ZEOP-DnD	1100	HC	Ozonias	2000
13	Nippon Paper	Japan	Yufutsu	Kraft	HW	ZD-Ep-D	520	MC	Ozonias	2000
14	Oji Paper	Japan	Nichinan	Kraft	HW	Z-Eop-P-D	750	HC	Ozonias	2001
15	Nippon Paper	Japan	Yatsushiro	Kraft	HW	A-Z/D-Eop-D	600	MC	Wedeco	2003
16	Mondi	Slovakia	Ruzomberok	Kraft	HW/SW	ZEop-D-P	1300	HC	Wedeco	2004
17	Oji Paper	Japan	Tomioka	Kraft	HW/SW	2 lines = ZD-Eop-D	800	MC	Wedeco	2005
18	Marusumi	Japan	Mishima	Kraft	HW	ZDo-Eop-DnD	700	MC	Wedeco	2006
19	Daio Paper	Japan	Mishima	Kraft	HW	A-Ze-P-D	1600	HC	Wedeco	2006
20	Sniace	Spain	Cantabria	Sulfite	HW	ZE-P	240	HC	Wedeco	2007
21	Nippon Paper	Australia	Maryvale	Kraft	HW	ZD-E-D	500	MC	Ozonias	2007
22	ITC	India	Bhadrachalam	Kraft	HW	Line 2 = Ze-D-Eop-D Line 3 = Ze-DP	300 400	HC	Wedeco	2008
23	Celtejo	Portugal	Vilha Velha de Rodao	Kraft	SW/HW	Ze-D-D Ze-P-P Ze-D-P	720	HC	Wedeco	2008

I. Pulp mills using ozone bleaching in their fiber line.

EXPERIMENTAL

Pulp samples

For this experiment, an oxygen delignified *Pinus radiata* kraft pulp was bleached using several bleaching sequences. The pulp sampled after oxygen delignification (OO) had a kappa number of 10.6 and a viscosity of 20.5 mPa.s. (The current bleaching sequence in the mill is a conventional DEpDD.)

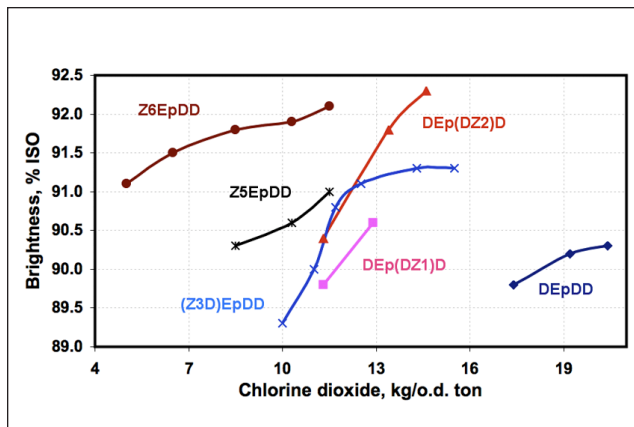
Reagents and bleaching stages

Ozone was produced in a laboratory ozone generator from pure oxygen at a concentration of 50-60 mg/L. Chlorine dioxide also was produced in the laboratory from the reaction between sulfuric acid and sodium chlorite at a concentration of 8 g/L in water. For practical reasons, the Z stages were carried out at high consistency. The ozone treatment was carried

out in a rotating spherical glass reactor at 20°C to 80°C. Ozone charges varied from 1 to 6 kg/o.d. ton of pulp. D stages were carried out at 10% pulp consistency in plastic bags placed in a thermo-regulated water bath. D0 stages were carried out at 50°C, with a retention time of 1 h. D1 stages were carried out at 75°C, with a retention time of 2 h, and D2 stages were carried out at 80°C for 3 h. Ep stages were run at 70°C with peroxide and sodium hydroxide.

Brightness, viscosity, and physical properties (bulk, tensile, and tear resistance) of pulp that had been bleached and then refined with a PFI mill were measured to ISO standards. Before viscosity measurement, the pulp was reduced with 2% sodium borohydride and 1% sodium carbonate at 10% consistency and room temperature for 30 min. The post-process color number was the difference ($\times 100$) between light

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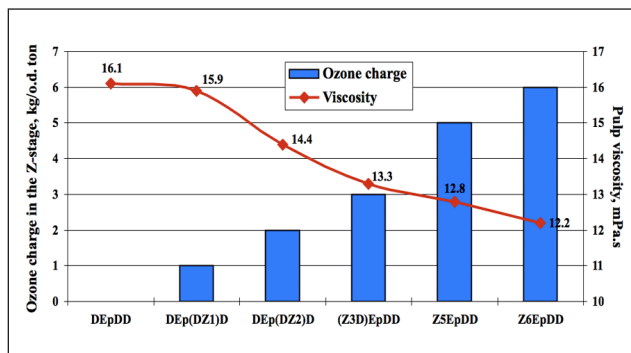
1. Brightness development of the bleaching sequences.

absorption and scattering (k/s) after aging at 105°C for 2 h, 24 h, and 48 h.

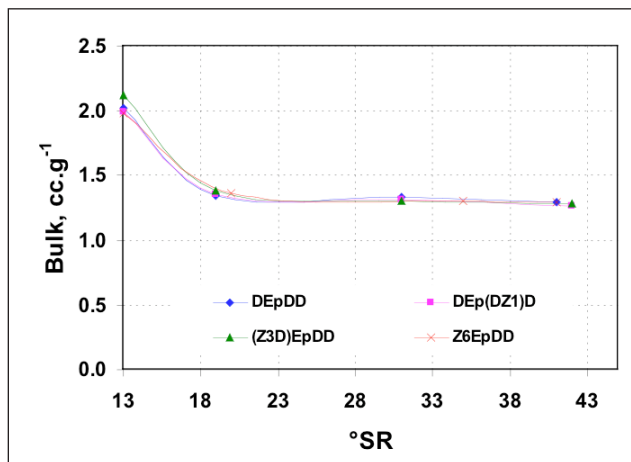
RESULTS

Ozone bleaching was investigated at different locations of the bleaching sequence with ozone charges from 1 kg/o.d. ton (DEp[DZ1]D) to 6 kg/o.d. ton (Z6EpDD). The goal was to characterize the effect of ozone regarding brightness development and pulp quality. A reference pulp bleaching sequence was carried out using the mill's operating conditions. Chemical consumption figures, brightness, viscosity, mechanical, and optical properties were measured to characterize the effect of ozone. **Figure 1** shows the main results obtained for brightness development of each bleaching sequence. As shown, ozone bleached pulps easily reached the brightness target of 90% ISO. To compare chemicals consumption and pulp quality, the bleaching chemicals charges were adjusted to achieve more or less the same brightness (close to 90% ISO) (**Table II**).

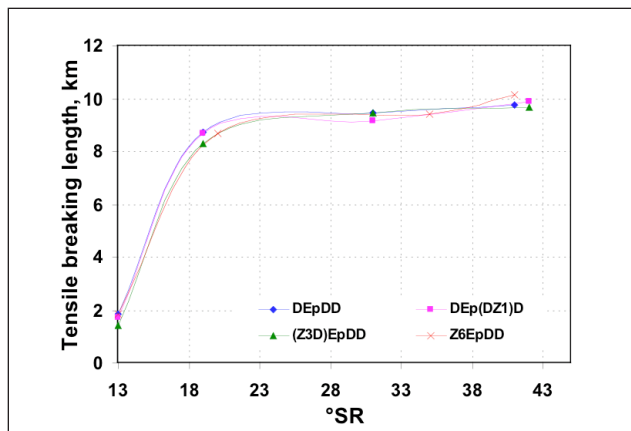
To quantify pulp quality, pulp producers measure the viscosity of the final bleached pulps. **Figure 2** shows the correlation between bleached pulp viscosity and ozone charge. Viscosity starts to drop where the ozone dosage is higher than 2 kg/ton of pulp and is not affected by the bleaching sequence (DEp[DZ1]D) with the lowest ozone charge when compared with the reference pulp. This confirms that using a lower ozone dosage can be a good approach to avoid impairing final pulp quality.



2. Ozone charge versus pulp viscosity after final bleaching.



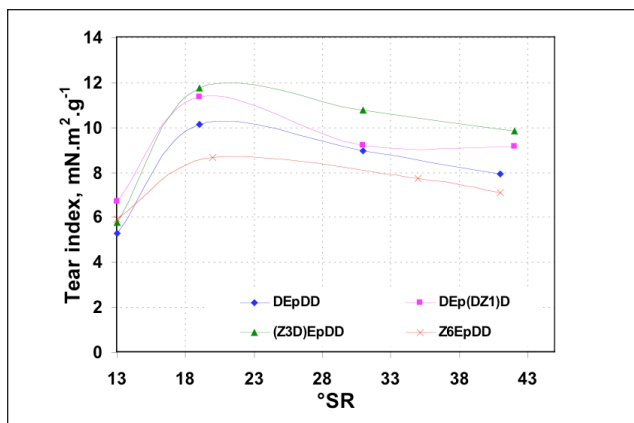
3. Bulk versus beating on control and ozone bleached pulps.



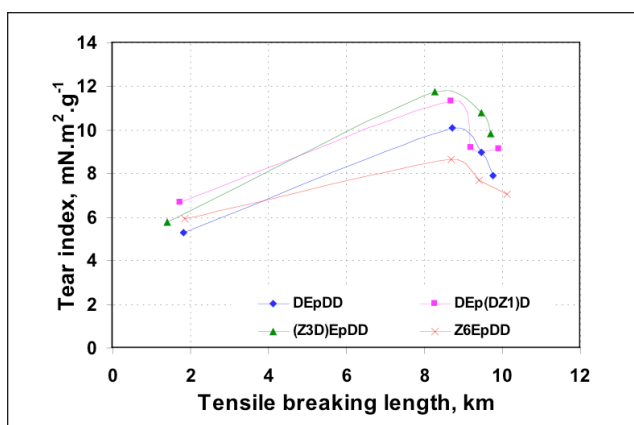
4. Effect of ozone treatment on tensile strength.

Sequence	DEpDD	DEp(DZ ₁)D	DEp(DZ ₂)D	(Z ₃ D)EpDD	Z ₅ EpDD	Z ₆ EpDD
Ozone, kg/ton	0	1	2	3	5	6
ClO ₂ (as pure), kg/ton	20.4	12.9	11.3	11.3	8.3	5
NaOH, kg/ton	10.9	10.9	10.9	10.9	10.9	10.9
H ₂ O ₂ , kg/ton	3.1	3.1	3.1	3.1	3.1	3.1
Brightness, %ISO	90.3	90.6	90.4	90.4	90.3	91.1
Viscosity, mPa.s	16.1	15.9	14.4	13.3	12.8	12.2

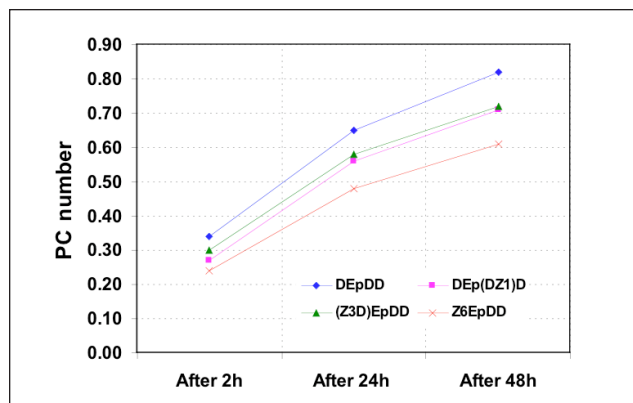
II. Chemicals consumption, brightness, and viscosity.



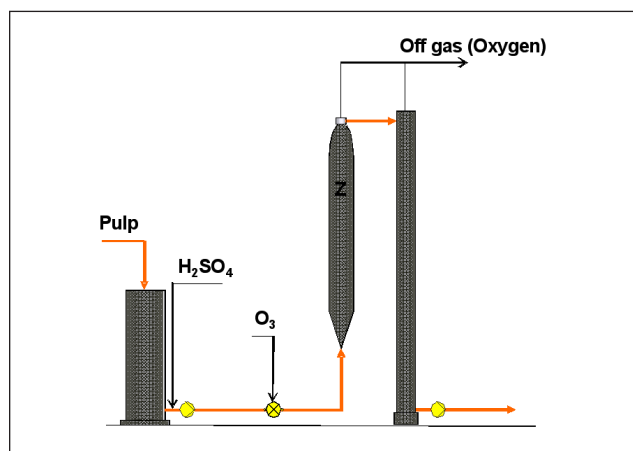
5. Effect of ozone treatment on tear strength.



6. Tensile versus tear index.



7. Brightness stability upon heat exposure.



8. Z-stage at medium consistency.

Bulk, strength, and optical properties of the reference bleached pulp after DEpDD were measured and compared with those of ozone bleached pulps from the DEp(DZ₁)D, (Z₃D)EpDD, and Z₆EpDD sequences using 1, 3, and 6 kg ozone/ton of pulp, respectively (**Figs. 3–6**). Bulk was not affected (Fig. 3). Tensile and tear strength were not modified by the ozone charge, and only a drop in tear could be observed for the highest ozone charge (Z₆EpDD). Pulps bleached by the DEp(DZ₁)D and (Z₃D)EpDD sequences had at least equivalent or slightly better mechanical properties than the reference pulp. A lower pulp viscosity, as in the case of the (Z₃D)EpDD sequence, does not necessarily mean lower pulp strength, although pulp viscosity is generally correlated to the strength properties of the pulp. Many other studies show that viscosity might not be an accurate indicator of pulp strength, especially where ozone bleaching is concerned [8,9]. To complete the pulp quality assessment, optical properties of the bleached pulp, such as brightness stability upon heat exposure, were assessed. **Figure 7** shows that ozone treatment improves brightness stability, especially in the case of high ozone dosages.

These results are in accordance with recent studies [9,10] demonstrating differences in the behavior of ozone compared with chlorine dioxide. One explanation could be that

ozone has eliminated substances having a negative effect on brightness stability, such as extractives, and remaining chromophores, such as quinones [11].

Economic assessment

To highlight the potential economic benefit of using ozone on softwood (*P. radiata*) pulp, a detailed assessment was performed using the previously obtained results and the data (energy and chemicals cost) from the pulp mill producing about 500,000 tons/year of bleached pulp.

Ozone and chlorine dioxide

To keep the bleaching process simple and to reduce investment cost as much as possible, an easy solution is to combine the ozone (Z) and chlorine dioxide stages (D) into one single bleaching stage [12,13]. Combining Z and D together is a good choice in terms of investment cost. If a (ZD) sequence is used, for example, the ozone stage is compact, requires an MC-pump and a mixer unit, and can be located in front an existing D-stage without any washing in between (**Fig. 8**). Ozone is introduced into the pulp at medium consistency (MC). As a result of efficient mixing and fast chemical reaction, the reaction time is a few seconds and the pulp at the

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outlet of the blower can be sent directly to the chlorine dioxide mixer (in a [ZD] configuration) without a washing step in between. No additional chemical for pH adjustment before or after ozone and no intermediate washing between ozone and chlorine dioxide are needed. Several mills in various parts of the world have successfully implemented (DZ) or (ZD) stages, mainly for hardwood pulp bleaching [1,2]. From an environmental perspective, by adopting (DZ)- or (ZD)-based bleaching, the mills are in a position to gradually upgrade their sequences to meet evolving effluent standards or market demands, while minimizing the risks of making soon-obsolete investments.

Replacement ratio

A critical parameter in assessing the economic benefit of the use of ozone is its ability to replace chlorine dioxide. The replacement ratio of chlorine dioxide by ozone is used to assess the two chemicals when compared at the same performance or efficiency levels for pulp delignification and bleaching. Such a ratio depends on the following:

- type of cooking and bleaching sequence
- type of raw material (hardwood, softwood, nonwood fibers)
- location of the ozone stage in the whole process
- quantity of chemicals used (chlorine dioxide and ozone)
- final brightness

In terms of theoretical oxidative bleaching ability, 1 kg of ozone represents 125 oxidation equivalents (OXE); for chlorine the number is 74.12 OXE/kg. This implies a theoretical bleaching ability per kilogram that is about 1.7 times higher for ozone than for chlorine dioxide. In practice, industrial-scale comparison of ECF bleaching using only chlorine dioxide on the one hand, and a combination of ozone and chlorine dioxide on the other, has shown the application of 1 kg of ozone to be equivalent to about 1.5 to 2.5 kg of pure chlorine dioxide when ozone is used for delignification [1,2]. A recent example is a mill in India that has been efficiently applying ozone to *Eucalyptus* pulp at high pulp consistency. This mill

has adopted a light-ECF bleaching sequence. During the start-up phase, bleaching was carried out at conventional ECF, without the ozone stage in operation, thereby making it was possible to show that each kilogram of ozone could substitute for up to 2 kg of chlorine dioxide.

Table III summarizes the values obtained for the (ZD) EpDD and DEp(DZ)₁D bleaching sequences for the softwood pulp bleached with ozone in this study. The replacement ratio strongly depends on the ozone dosage applied to the pulp, and on the placement of the Z-stage in the sequence. In the case of the (Z₃D)EpDD bleaching sequence, the action of ozone and chlorine dioxide, in the (ZD) stage, is to finalize pulp delignification before the alkaline extraction and final bleaching phases. In that case, each kilogram of ozone replaces 2.9 kg of pure chlorine dioxide. Such a value is consistent with results from several other bleaching studies of softwood and hardwood pulps [12-14].

Table III shows that the replacement ratio significantly increases when ozone is used at the end of the bleaching sequence. As pulp delignification is more or less completed after the alkaline extraction stage (Ep), ozone acts as a brightening agent to efficiently remove the last colored compounds and by-products remaining in the pulp. To preserve cellulose from chemical oxidation, the ozone charge must be reduced. Therefore, ozone becomes an excellent complement to bleaching chemistry based on chlorine dioxide, which normally requires a long retention time and high chemical dosage, especially if high brightness is required. Unlike chlorine dioxide, however, ozone does not form colored by-products. Those chemical considerations would explain why the potential of ozone used at the end of bleaching proves better than that of chlorine dioxide, which can form colored groups (quinones) [10].

Operating costs

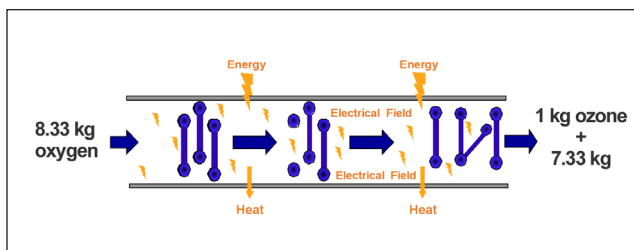
As with the replacement ratio, ozone investment and operating cost soon becomes a critical issue, and obtaining reliable information about those costs is fundamental in the decision-making process. The operating cost of on-site chlorine dioxide production is mainly linked to the purchasing cost of chemical precursors such as sodium chlorate, a reductive agent (generally methanol or peroxide) and sulfuric acid.

Pulp mill managers generally know the internal cost of chlorine dioxide use because most plants have continuous optimizing programs to reduce its use. The operating cost of chlorine dioxide use is mainly linked to the purchasing cost of chemical precursors such as sodium chlorate, a reductive agent, and sulfuric acid, and to the technology used for on-site generation of methanol and peroxide. However, cost comparisons of chlorine dioxide to ozone also must account for the operation and maintenance expenses of the chlorine dioxide plant and those related to the purchase, delivery, and storage of the chemicals on site. Concerning ozone, three components have to be considered in the variable cost, as follows:

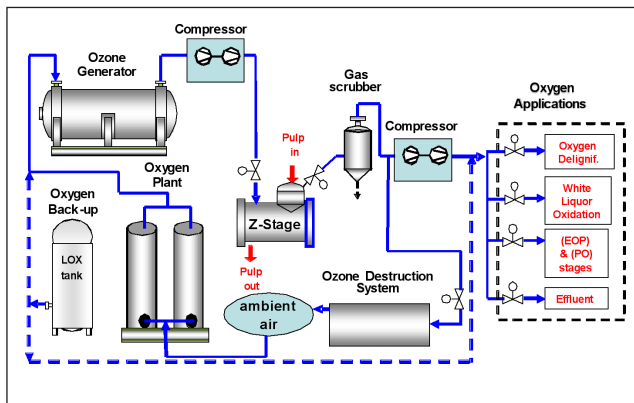
- oxygen requirement from a vacuum pressure swing ad-

Sequence	DEpDD	DEp (DZ ₁)D	DEp (DZ ₂)D	(Z ₃ D) EpDD
Ozone charge, kg/ton	0	1	2	3
ClO ₂ charge, kg/ton	20.4	12.9	11.2	11.7
Replacement ratio	—	7.5	4.6	2.9

III. Replacement ratio of chlorine dioxide with ozone in bleaching of *Pinus radiata*.



9. Ozone formation in an electric field.



10. Ozone and oxygen production, including oxygen reuse from the Z-stage.

sorption (VPSA) or liquid oxygen (LOX) production facility

- energy for ozone generation, pulp mixing, and pumping
- operation and maintenance

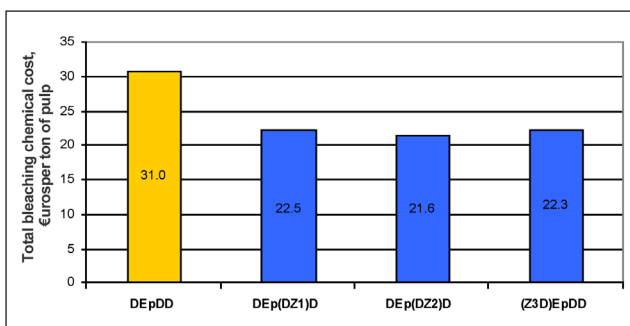
For industrial application, such as chemical pulp bleaching, ozone is generated at a concentration of about 12% by weight in oxygen to reach the optimal figure between investment and variable costs (oxygen and energy). To generate ozone in such conditions, 1 kg ozone requires about 8.33 kg of oxygen and 10 kW•h energy. **Figure 9** describes the principle of ozone generation.

Depending on the local cost of oxygen (from VPSA or LOX plant) and energy, the operating cost (maintenance included) for ozone generation is generally in the range of EUR 0.8 per kg of ozone. The off-gases vented from the Z-stage can be re-used in the oxygen consuming applications of the bleaching fiber line such as oxygen delignification, EOP-stage, white liquor oxidation (WLO) or other applications (wastewater treatment). It is the case for two-thirds of the 28 ozone bleaching systems in operation in the world. **Figure 10** shows a typical layout of an MC ozone system, including oxygen reuse.

Recycling oxygen should be viewed as a means to “save” oxygen and to reduce the cost of ozone, but this possibility has to be balanced with additional investment (compressor unit, piping, etc.), especially when high pressure is required for applications such as oxygen delignification. Defining the most optimized solution for oxygen reuse is done in connection with the local conditions and constraints of the pulp mill

Variable Costs, EUR/Kg	Oxygen Reuse	
	No	Yes
Oxygen for ozone production	0.33	0.05
Energy for ozone production	0.46	0.46
Energy for ozone compression	0.12	0.18
Energy for pulp mixing & pumping	0.24	0.24
Operation & maintenance	0.10	0.12
Ozone - Total	1.25	1.05
Chlorine dioxide	1.3	1.3

IV. Variable cost of chlorine dioxide and ozone in euro per kg (local cost: energy EUR 0.04/kW•h, oxygen (vacuum swing absorption) EUR 0.04/kg).



11. Bleaching costs comparison, including the chemical cost of chlorine dioxide, ozone (operating cost without oxygen reuse), peroxide (EUR 0.55/kg, 100% based), and sodium hydroxide (EUR 0.25/kg).

and always meets a specific situation.

In the particular case of the mill producing bleached softwood (*P. radiata*) pulp, the local cost for energy and chemicals is taken into account in the calculation. In addition to the specific cost of ozone generation, the variable cost must also include the energy requirement for ozone compression, pumping and mixing of ozone into the pulp, and the operation and maintenance of the whole installation. **Table IV** summarizes these costs, showing the difference whether the oxygen from the Z-stage is recycled or not.

Finally, the comparison must take into account the cost of the other chemical agents involved in pulp bleaching such as peroxide, sodium hydroxide, and sulfuric acid, which are provided by the pulp mill. **Figure 11** shows the results when the bleaching cost of current ECF bleaching sequence OOD(Eop) DD is compared with several bleaching options at a given brightness target of 90% ISO. Depending on the ozone charge and the position of the Z-stage in the bleaching sequence, between 25% and 30% of the total bleaching cost can be saved (Fig. 11). This is real progress regarding the optimization plan to decrease variable costs for pulp production. To finalize the calculation, such a chemical saving should be balanced with the investment for a complete ozone stage, including the equipment for ozone generation, pulp mixing, etc., and additional oxygen capacity. The

	DEpD(Z ₂ D)	
	Oxygen Reuse	
	No	Yes
Chemical savings, EUR/ton of pulp	9.5	9.9
Total investment, EUR	6,000,000	7,000,000
Payback time, months	15.22	17.02
Gain per year, EUR	4,732,000	4,934,200
Net gain 5 years, EUR	17,660,000	17,671,000
Net gain 10 years, EUR	41,320,000	42,342,000

V. Economic benefits with the DEp(DZ₂)D compared with the current DEpDD bleaching sequence.

DEp(DZ₂)D bleaching sequence using 2 kg ozone is chosen to lower as much as possible investment cost. **Table V** shows the expected expenses, economic benefit, and payback time if the pulp mill implemented such a sequence.

In this example, the mill has a production capacity of 500,000 tons/year. Depending on the reuse or not of oxygen after the ozone stage, the complete investment (Ozone production, Z-stage, compressor unit, local part) is EUR 6-7 million. In this case, the annual saving is close to EUR 5 million, with a payback period lower than 18 months for the total investment.

To increase the benefit further, the mill could shut down one of the final chlorine dioxide stages and investigate a short bleaching sequence, such as DEp(ZD), instead of the conventional DEpDD.

CONCLUSIONS

Ozone is one of the most cost-effective bleaching chemicals available to the pulp and paper industry. Reliable on-site generation of tons of ozone per day, combined with efficient pulp bleaching systems and low chemical costs, are reasons ozone bleaching has become an established technology and has been chosen in many projects for hardwood pulp bleaching. Considering the specific constraints of softwood bleached pulp production, an interesting development is to reconsider the use of ozone on these pulps at the end of the bleaching sequence. With an ozone operating cost very similar to those of chlorine dioxide, it is possible to define a new bleaching strategy to maximize the replacement of chlorine dioxide with ozone, keeping in mind the pulp quality constraints.

From a chemical point of view, ozone is the ideal complement of chlorine dioxide for final pulp bleaching, and a high brightness level can be achieved at a limited bleaching cost. Both chemicals can easily be combined at the end of the bleaching sequence. Practically, a medium consistency Z-stage is cheap, compact, and easy to integrate into an existing fiber line. Even a mill that is equipped with sufficient chlorine dioxide capacity could achieve savings in bleaching costs by introducing a “small” Z-stage in its bleaching sequence. For pulp mills having, for instance, a capacity expansion project, the benefit will be higher because investment and variable cost of the Z-stage will be balanced with the investment of additional chlorine dioxide production capacity, including process equipment for a chlorine dioxide stage.

Another benefit favoring ozone bleaching is that ozone generation is a “real” on-site technology that gives a mill greater independence from the chemicals market since the main variable cost is, ultimately, local energy when oxygen is also produced on-site. Moreover, bear in mind that ozone does not generate any hazardous by-products and contributes to the reduction of water requirements and total AOX emissions. **TJ**

ABOUT THE AUTHORS

The objective of this research was to widen the use of ozone bleaching, which is one of the best available technologies regarding process efficiency and environmental performance. Ozone bleaching is already considered a well-established technique for pulp delignification. A remaining field of investigation is the use of this chemical at the end of the bleaching stage to prove its brightening ability.

Because ozone is known for its potential aggressiveness toward fiber strength, especially when softwood pulp is concerned, the challenge is to point out that limited ozone dosages maximize savings in operating costs while keeping fiber integrity.

The most interesting point shown by the study is the ability of ozone to complement the bleaching chemistry based on chlorine dioxide during final pulp

bleaching.

By implementing an ozone bleaching stage at the end of the bleaching sequence, a pulp mill can obtain significant savings in bleaching operating costs at limited investment costs.

As technology for ozone generation and pulp mixing is already well optimized, the next step will consist in directly moving to full-scale application.



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LITERATURE CITED

1. Hostachy, J.C., Coste, C., and Serfass, R., *Proceedings of the 13th Ozone World Congress*, International Ozone Association, Scottsdale, AZ, USA, 1997, vol. II, p. 277.
2. Vehmaa, J., and Pikka, O., *Proceedings of the 8th International Conference on Pulp, Paper, Conversion and Allied Industry*, Paperex 2007, Delhi, India.
3. Winnerstrom, M., and Carre, G., *Proceedings of the 2005 International Pulp Bleaching Conference*, SPCI, Stockholm, Sweden.
4. Toven, K., *TAPPI J.* 2(2): 3(2003).
5. Fuhrmann, A., Li, X-L., and Rautonen, R., *Proceedings of the 1996 International Pulp Bleaching Conference*, TAPPI PRESS, Atlanta, p. 71.
6. Seisto, A., Poppius-Levlin, K., and Fuhrmann, A. in *Cellulosic Pulps, Fibres and Materials* (J. Kennedy, G. Philips, P. Williams, et al., Eds.), Woodhead, Cambridge, UK, 2001, pp. 137-147.
7. Hostachy, J.C., and Araujo, O., *Österreichische Papierfachtagung 2008*, Deutscher fachverlag, Frankfurt am Main, Germany.
8. Chirat, C., Mishra S.P., and Lachenal, D., *Proceedings of the 2008 International Pulp Bleaching Conference*, PAPTAC, Québec City, QC, Canada, p. 181.
9. Chirat, C., Lachenal, D., Mishra, S.P., et al., *14th International Symposium on Wood, Fiber and Pulping Chemistry*, TAPPSA, Durban, South Africa, 2007, Conference CD.
10. Lachenal, D., Pilon, G., and Chirat, C., *Pulp Pap. Can.* 107(9): 1(2006)
11. Eriksson, T., and Gierer, J., *J. Wood Chem. Technol.* 5(1): 53(1985).
12. Chirat, C., and Lachenal, D., *TAPPI J.* 80(9): 209(1997).
13. Chirat, C., Lachenal, D., Angelier, R., et al., *J. Pulp Pap. Sci.* 23(6): 289(1997).
14. Millar, H., Ruiz, J., Freer, J., et al., *J. Chil. Chem. Soc.* 48(1): 2003, available online at http://www.scielo.cl/scielo.php?pid=S0717-97072003000100006&script=sci_arttext.

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