PULP BLEACHING WITH OZONE
INDUSTRIAL ACHIEVEMENTS & PERSPECTIVES

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ABSTRACT

First industrial production of ozone bleached pulp started almost 20 years ago in connection with increasing environmental pressure during the Total Chlorine Free (TCF) wave. Like many other new technologies, ozone bleaching did not immediately reach its optimal efficiency from a technical viewpoint, but had to face several issues during its early years. By improving mixing technology, better understanding ozone chemistry on pulp components and tuning the whole process, the so-called ECF-Light bleaching sequences - including an ozone stage - made it possible to deliver a pulp quality similar or better than conventional ECF bleaching would do. Today the choice of ozone may still be motivated by ecological constraints but it is mostly justified by economical savings resulting from chemicals costs cut-off. Actually, both targets are reached simultaneously when implementing an ozone bleaching stage. Through several industrial results, this work describes process improvements in ozone bleaching since 1992, and shows results obtained for pulp quality and bleaching chemical costs from modern bleaching fiberlines including one mill located in India. All these elements highlight why should ozone should now be considered as a keystone of modern pulp bleaching processes.

But the story is not finished and developments performed the last two years regarding both ozone generation technology and ozone application are also presented in this paper. Contrary to conventional ECF bleaching mainly based on chlorine dioxide which has already reached its ecological terminus, Green Bleaching is certainly the best answer to the dilemma between short–term profitability and process flexibility for production of bleached pulp, and long-term vision guided by principles of responsibility to preserve environment, resources and finally biodiversity.

INTRODUCTION

The first industrial pulp bleaching line including an ozone stage started 19 years ago. Today there are 22 mills worldwide using what is commonly named light-ECF bleaching. Among those 22 mills, 16 produce solely hardwood pulps, 4 produce both softwood and hardwood pulps while SCA mill in Östrand (Sweden) and Rosenthal mill in Blankenstein (Germany) produce exclusively softwood pulp [1]. 13 mills started ozone bleaching in the early years of the 21st century and 3 mills equipped two of their bleaching lines with ozone: Oji Paper mill in Tomioka (Japan), Fibria mill in Jacarei (Brazil) and ITC mill in Bhadrachalam (India). Fibria mill in Jacarei selected ozone bleaching in 2002 for its 2,500 a.d. tons/day new line C after having operated ozone bleaching as from 1995 on its 900 a.d. tons/day line B. Fibria just decided beginning of 2011 to renew its ozone delivery contract for line B for additional 6 tons per day. This decision clearly shows that ozone bleaching has met all requirements and expectations on line B for 7 years.

In Angust 2011, Lenzing just started a new ozone installation and four ozone generation systems have been contracted and will start operating in 2012 for:

- a 700,000 a.d. tons/year capacity Chinese greenfield mill owned by Oji Paper (Oji Paper already uses ozone in its Japanese mills);
- a new dissolving pulp mill in Europe;
- 2 pulp production capacity increases in Brazil.

Ozone bleaching is efficiently used on hardwood and softwood pulps, on kraft and sulfite pulps dedicated to all kinds of final applications. Pulp producers do not always evaluate the significant ecological advantages of ozone-based bleaching sequences over the traditional ECF bleaching sequence D0-Eop-D1-D2 (or its derivates); the quality of wastewater is drastically improved [2,3] as it is possible to lower bleaching effluents to 4-6 m3/a.d. ton [4]. Of course investors always focus on the return on investment… and it has now become clear to all ozone users that bleaching costs are reduced by 20-32% when introducing an ozone stage in an ECF bleaching line [3,5,6,7] and even more in the case of a TCF bleaching [8]. The high bleaching efficiency of ozone allows a drastic reduction in the consumption of expensive bleaching chemicals - chlorine dioxide in ECF bleaching and hydrogen peroxide in TCF bleaching as well as sodium hydroxide in both cases – and the implementation of ozone bleaching also results in the reduction of steam requirements during the bleaching process. The return on investment in the replacement of a D0-stage by an ozone stage Z corresponds to a payback period of between 2 and 4 years [1,6].

Without affecting the pulp strength properties in comparison with conventional ECF sequences, bleaching with an ozone stage additionally gives a wide range of opportunities by:

- Making very high brightness levels possible (92-93% ISO) [2];
- Decreasing brightness reversion [2,8,10];
- Reducing drastically the extractive content [10,11] by 50-75% [8,12];
- Reducing energy requirements in the refining by at least 10% [3,13];
- Controlling viscosity in viscose pulp production;

The industrial use of ozone has already undergone a long string of improvements and developments. Like for other new technologies, ozone bleaching did not immediately reach its optimal technical efficiency but faced several issues during its early years. All the same, achievements of ozone bleaching have improved year in year out and it is now a well proven technology. Nevertheless, some pulp producers still keep in mind the difficulties faced in the early years and unfortunately, this still represents a very serious drawback towards the modernization of their pulp mills. By doing a brief survey of ozone application in pulp bleaching development over the past 20 years, the present article aims to draw attention to industrial practices and technologies that helped ozone bleaching becoming one the most advanced technology.

OZONE GENERATION

Ozone generation is a pure on site technology requiring only energy and oxygen (usually also produced on site from a VPSA plant). Ozone (O3) is produced from oxygen (O2) in an electrical field at a concentration of 12% by weight according to figure 1.

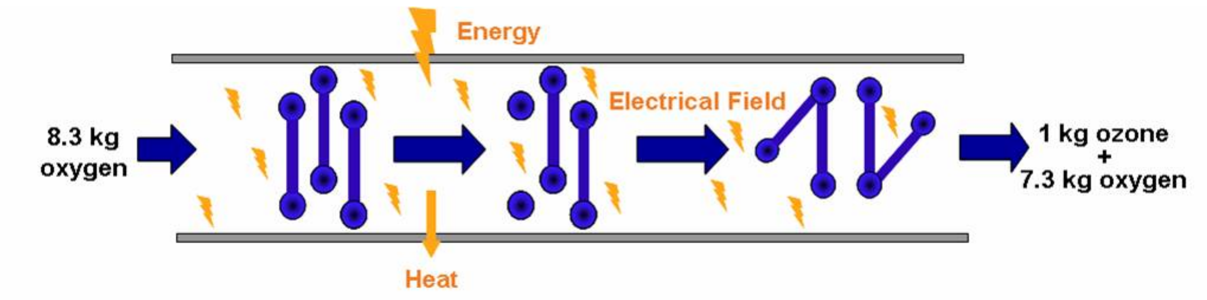

Figure 1 - Ozone formation in an electrical field

Modern ozone generators are 50% more efficient than the ones used in the first ozone pulp bleaching applications. Compact and modular ozone plants (figure 2) were specially designed for the pulp and paper industry and they are able to produce up to 250 kg O3/h (6 tons per day) per unit.

Today ozone production only requires 7 to 8 kWh per kg of ozone and as a result, 1 kg ozone is now cheaper than 1 kg of chlorine dioxide. Based on a "plug and play" principle, modern ozone generation units are easy to operate and can deliver the full ozone capacity in less than one minute with an availability higher than 99%.

Figure 2 – Z-Compact System producing 5 tons per day ozone at ITC Bhadrachalam (India)

HIGH CONSISTENCY OZONE BLEACHING

The first commercial high consistency (HC) ozone bleaching started in 1992 at the Union Camp mill in Franklin (Virginia, USA). According to the C-Free® process implemented there, the pulp was pH adjusted, pressed to high consistency (40%), fluffed and transferred to the ozone paddle reactor operating at atmospheric pressure [14]. The C-Free® was provided by Sunds Defibrator until the late 90's in the USA, Sweden, South Africa and Germany.

Modern HC ozone bleaching uses the ZeTrac technology provided by Metso Paper which is a much simplified version of the C-Free® (fig. 3) [5]. The experience gained from the first industrial installations has shown that ozone requires very short (around 1 minute) contacting time with the pulp and that a 5-10 minutes extraction stage after the Z-stage is in most cases sufficient. These observations permitted to reduce the size of reactors and so to lower investment costs. Then the plug screw feeder, the refiner fluffer and the washing stage prior to the extraction stage could all be eliminated. These drastic simplifications led to significant reduction of the capital expenditure, energy requirements, maintenance costs as well as effluent volume [5].

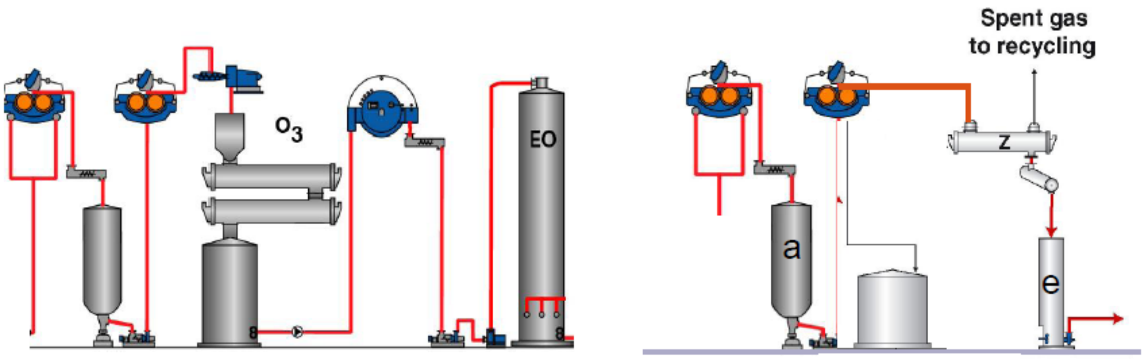

Figure 3 - HC ozone bleaching in the 90s and today [15]

Fig 3 above shows the principle of the modern ZeTrac system. The pulp is acidified and then pressed to high consistency (38-42%). Such a high consistency is a prerequisite to facilitate the rapid contact between ozone gas and well fluffed pulp and so preserves the reaction efficiency. Once dewatered, the pulp is fluffed in a shredder screw on the top of the press and fed by gravity into the reactor. Ozone is added to the reactor which is operated at a pressure slightly below atmospheric. After the reactor, the pulp is diluted with alkaline liquor.

MEDIUM CONSISTENCY OZONE BLEACHING

Principle of medium consistency (MC) ozone bleaching is coming from the application of oxygen using different operating conditions and metallurgy. As a gas, ozone needs to be efficiently mixed with the pulp (high shear mixing) to ensure a homogeneous reaction. A typical MC ozone stage (fig. 4) features a MC pump that feeds the pulp to the ozone stage, one or two ozone mixers in series, a pressurized reaction tube, a flow discharger at the reactor top and a blow tube [11]. Because of pulp consistency between 8 to 12% inducing a large amount of filtrate around the fibres, and to ensure a certain gas/liquid ratio in the heart of the mixer, the reaction must take place in a pressurized (7-8 bars) mixer and reactor. Consequently the total gas flow (oxygen + ozone) must be compressed accordingly.

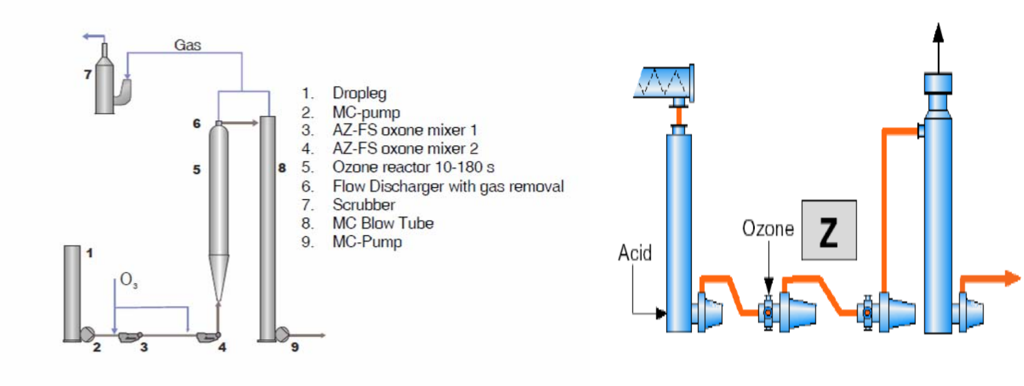

Figure 4 - Typical configuration of MC ozone stage (Source Andritz and GL&V) [11]

It is noticed that the main ozone reaction takes place during high shear mixing while the "reactor" has limited effect on the ozone reaction but mainly guarantees a stable flow to the blow tube [11]. It is now possible to decrease the gas pressure from 12 bars to 9 bars and thus reduce operating costs.

Improvements in medium consistency (MC) ozone bleaching consist in fact of alterations to the ozone mixer, which are is the core of the MC Z-stage since pulp quality depends on its efficiency. In former time, very few mills facing quality issues were those where the first MC ozone bleaching technique was implemented: this was mainly due to a non homogenous mixing combined or not with inadequate mixing conditions which mechanically affected the fibres.

Andritz, GL&V and Lenzing Technik are the three suppliers of MC ozone mixers and all medium consistency Z-stages are designed according to the same principles. Industrial practices show that two mixers in series are required for an application of 3-6 kg per ton ozone dose to get the optimal bleaching efficiency, while one single mixer is sufficient for lower ozone charges.

Andritz and GL&V improved efficiency of former Ahlström and Kvaerner ozone mixers respectively. By reducing the gas bubbles size without making any fundamental change in the design of the mixer but only increasing turbulences and mitigating the mechanical action [12], it makes the mixing a lot more homogenous and maintains pulp strength all along ozone treatment. By supplying the complete scope of equipment found in a fiberline, Andritz can potentially integrate MC ozone is a wide range of bleaching sequence in combination or not with acidic or chlorine dioxide stage depending on raw material, pulp quality requirement and environmental aspects. Additional improvements have been performed the last years to optimize further the MC ozone stage in terms of energy consumption, pulp consistency and ozone dosage.

Lenzing started a MC ozone mixing system from Kvaerner in 1992 and since then has investigated all possible improvements in MC ozone bleaching. They have been pioneers designing their own ozone MC mixers (called Eccentric Mixers) implementing the revolutionary idea of an asymmetric design to increase both fluidisation of the pulp and retention time [16]. Lenzing upgraded its 2 bleaching lines in 2004 with its new mixers and the use of the new mixing technology resulted in a 2.5 ISO brightness points increase for the same ozone dose. Actually, after optimization, the mill reduced its bleaching chemical costs by 50% on line 1 and 38% on line B [16]. Increasing fluidization time improves ozone reaction but also increases specific energy consumption.

PULP QUALITY

Since the first commercial ozone bleaching installation was started, enhancements to the ozone bleaching process have been conducted jointly by laboratories on the chemical side and by both the industry and equipment suppliers on the operational and technical sides. No doubts that improvements in ozone bleaching efficiency were boosted by the development of automatic control systems, mainly as a result of the electronics impressive achievements in terms of accuracy and reliability. It is now possible to adjust very precisely the ozone dosage, the pH, the retention time and the temperature in the Z-stage. These improvements now fully guarantee the pulp quality after ozone bleaching.

When ozone bleaching started to develop in the early 90's, the use of such a powerful oxidant in combination with yet non optimized process parameters (the most important issue being the mixing homogeneity) resulted sometimes in uneven pulp delignification and affected the pulp mechanical properties. Practices improved step by step and opportunities soon replaced difficulties… Yet many pulp producers still believe that the quality of ozone bleached pulps, especially softwood ones, is lower than traditional ECF bleached pulp quality. Since most of the mills using ozone are producing hardwood pulps, some people even believe that this evidence sustains the alleged lower strength of softwood ozone bleached pulps. The true explanation instead is rather simple: ozone bleaching is mostly implemented in Europe, Brazil, South Africa, Australia, India and Japan, all countries deficient in softwood resources. Thus, such an argument does not stand considering that 25% of the mills using ozone are producing softwood pulps. This proportion is not lower than the ratio of softwood/hardwood bleached pulps produced in those countries.

No significant difference could objectively be observed on the paper machine run except the saving in refining power requirement which obviously is lower for ozone bleached pulps [3,13].

On the other hand, numerous studies carried out during the 90's and in the more recent years have shown that the selectivity of ozone against lignin is very high. It is now established that the reaction rate of ozone with lignin is 1,000 times higher than the rate of cellulose oxidation or depolymerisation by ozone [15, 17]. This means that as long as there is some remaining lignin a well-operated ozone bleaching process does not impact the cellulose more than any other bleaching stage (a chlorine dioxide one for example). Those scientific results are confirmed by the following industrial experience of ozone bleaching.

In 1998, Domtar mill in Canada switched from the ECF O-A-D-E-DnD sequence to the light-ECF O-A-ZD-E-DnD sequence for bleaching pulp up to 93% ISO brightness. Comparing the two sequences, it was noticed "no impact on pulp mechanical strength or viscosity" and pulp DCM extractives content was reduced by 30-50% [9].

Mondi mill in Ruzomberok (Slovakia) produces hardwood and softwood pulps at 89% ISO brightness and switched in 2004 from a D-Eop-D-E-D bleaching to a ZEo-DnD one. It should first be noticed that there was only one washing stage (after ZEo) in the new bleaching. The mill compared hardwood and softwood pulp strength parameters of the new pulps with the ones of the former pulps set as the reference (100%). Only minor differences could be seen in standard pulp properties (table 1) [18].

	Hardwood	Softwood
PFI rev	89	90
Burst Index	100	97
Tear Index	92	90
Breaking Length	104	102
Tensile Index	102	102
Stiffness	93	94

Table 1 - Relative pulp quality for ECF-Z compared with ECF at 27°SR for both HW and SW [18]

Concerning hardwood pulp, energy requirements for refining dropped by 11%, burst was maintained, breaking length and tensile index increased while tear and stiffness decreased. Meanwhile, for softwood pulp, refining energy was again reduced significantly, tensile properties increased marginally while burst, tear and stiffness showed some reduction.

At this stage it is worth remembering that generally, the tensile index is increased by refining while the tear index follows the opposite trend and it is impossible to increase both of them at the same time. Nevertheless the mill reported that the paper machines runnability was not impacted and the final paper properties were even better than expected in term of stiffness [13]. Hardwood pulp properties were particularly excellent and the hardwood proportion in the paper machines furnish was increased over 90% [13]. In 2005 Ruzomberok set up a new world record for copy paper production at 1,500 m/min [13,18]. Of course, these two achievements would not have been possible with a lower pulp quality than before.

Moreover the mill has kept improving the Z-stage operation and its bleaching process by installing a pressurized (PO) stage in place of the last D stage in August 2008. Current pulp strength properties shown under figure 5 are excellent.

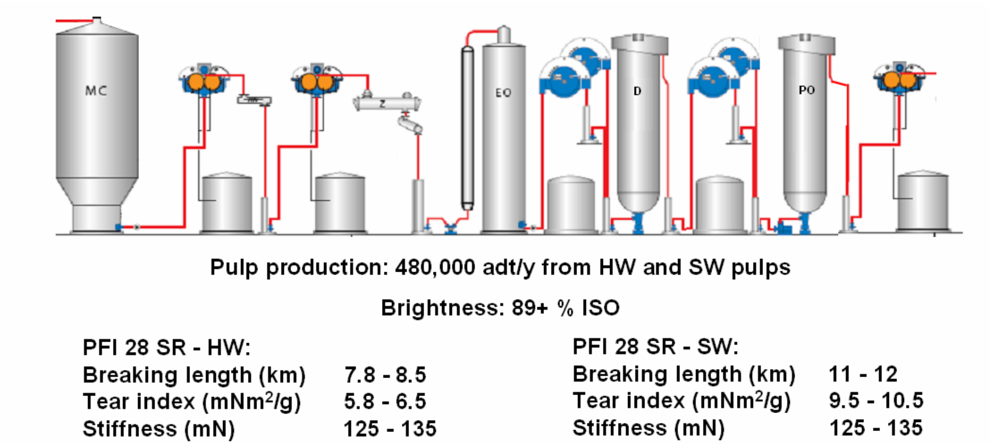

Figure 5 - Bleaching line at the Ruzomberok mill and pulp strength properties [1]

OPERATING PARAMETERS

Pulp temperature is an important operating parameter that has been tuned. Ozonation was initially carried out at 40°C in the 90s and such a low temperature was not very convenient as the Z-stage is located right after the 85-95°C oxygen delignification and before an alkaline extraction or a chlorine dioxide stage (after a few MC ozone stages) generally carried out at around 60-80°C. It is therefore necessary to cool down the pulp before heating it back.

It was thought that a higher temperature would lower the Z-stage efficiency, speed up the ozone decomposition, increase the negative impact of transition metals and ultimately decrease the pulp quality. Slowly, throughout industrial trials, it appeared that such fears were totally unfounded. Several results have demonstrated that for hardwood pulp the Z-stage temperature could be increased up to 60°C and sometimes even higher without any negative impact on pulp strength and brightness [9,13,18].

For example, data from Ruzomberok mill show that an increase of the Z-stage temperature from 43°C to 61°C gives a higher brightness (+1.8% ISO), a lower brightness reversion, a higher stiffness and a better ozone delignification efficiency with all other properties (PFI rev, Burst Index, Tear Index, Tensile Index and Bulk) unaltered (table 2) [13,20].

Temp in Z	43°C	43°C	58°C	61°C
Kappa number after Z(EO)	4.1	4.0	4.0	3.8
ClO_2 charge, kg/adt (DCS data)	24.5	23.5	24.7	24.4
Brightness, % ISO	85.9	85.2	86.6	87.7
Reverted Brightness, % ISO	81.8	82.2	83.9	85.9

Table 2 - Impact of temperature on the Kappa index at Ruzomberok [20]

The Domtar mill in Espanola first operated the Z-stage at 50°C. When they decided to increase the ozone stage temperature to 60°C, the delignification efficiency i.e. Kappa drop / kgO3 increased from 0.8 to 1.0 [9].

All hardwood pulp mills which set up an ozone stage in the past 5-6 years are running the Z stage at a 55°C minimum. This also resulted in significant steam savings. For example Mondi Ruzomberok reduced its steam requirements by 75% by running the Z-stage at 58-61°C [13].

Metso Paper has shown with industrial results that steam requirements for light-ECF bleaching are only 25% of steam requirements for conventional ECF bleaching in the case of eucalyptus pulp [8]. While the bleaching sequence DHT-Eop-D requires 249 kg/t of LP steam and 40 kg/t of MP steam, 65 kg/t of LP steam only are necessary for the Ze-DD bleaching sequence.

As an example, implementation of the ozone stage in Bhadrachalam led to a 50% drop in steam consumption in comparison to the former D-Eop-D bleaching sequence [21].

Steam savings are of course the highest in the case of hardwood pulp bleaching where usually a first A-stage (acidic) or DHT-stage (D-stage at hot temperature) is implemented. Such A or DHT stages have two objectives:

- Removal of hexenuronic acids (HexA) which are responsible for parasite chlorine dioxide consumption and brightness reversion;
- Cleaning the pulp from transition metal ions which are known to decompose peroxide and responsible for weakening of the cellulose during peroxide bleaching.

By removing metal ions, the A-stage effectively replaces the use of a chelating agent. Acidic stages were built prior to the ozone stage in the 90s at the UPM mill in Pietarsaari (Finland), at the Sateri mill in Bahia (Brazil), at the Fibria mill in Jacarei (Brazil) and at the Domtar mill in Espanola (Canada). But there is strong evidence that the implementation of an A-stage could reduce both pulp strength properties and pulp yield [22]. Nevertheless, bleaching sequences such as A-Z-D-P, A-Ze-PO or A-Eop-Z-P should be considered in case of high amounts of HexA.

Of course, there is no such problem of HexA in the case of softwood pulp bleaching. But the issue of transition metals remains and in the 90s Swedish mill SCA Östrand and the German Rosenthal mill in Blankenstein chose to start their bleaching sequence with a Q-stage (chelation). Such A-stages or Q-stages are costly because they require long retention time and the use of drastic operating conditions such as high temperature and acidity in the case of A-Stage. Industrial light-ECF and ozone based TCF experiences have yet shown that the installation of those A-stages or Q-stages could be avoided. Q stages could be only justified by the extensive use of peroxide being potentially decomposed by Iron and Manganese.

The HexA content is reduced by at least 60% in the ozone stage [23]. This makes the ozone stage even more efficient than any A-stage and it partly explains why ozone bleached pulps have a lower brightness reversion than other pulps.

Among the other parameters mentioned in the literature potentially affecting the efficiency of the ozone stage, it can be noticed:

- The carry-over inside the pulp especially with MC ozone bleaching, inducing ozone consumption in parasite reaction. Industrial feed-backs have shown that the sensitivity of ozone to carry-over is equivalent to those of chlorine dioxide explaining why the replacement ratio of chlorine dioxide by ozone is generally higher than 2. For example, in ITC (Bhadrachalam), 1 kg ozone replaces 5-6 kg Act. Chlorine [24].

- Raw material quality inducing potential scaling problems. In most of the cases, scaling is generally coming from high calcium content present in the raw material, and affected by the pH switch through the bleaching process. ITC (Bhadrachalam) was facing this problem after start-up [24], and successfully solved it implementing raw material debarking (decrease of Calcium from 15000 ppm to 5000 ppm) and additional acidic washing prior to the ozone stage. But scaling is not linked to ozone in particular. Similar problem has occurred in other Indian pulp mills having just converted their process to ECF bleaching without ozone.

BLEACHING SEQUENCES

Apart from the proven economical, technical and environmental advantages, the development of oxygen delignification as well as improvements in ozone bleaching and in the whole pulping process over the last 20 years, amazingly permitted to shorten the bleaching sequences by one, two or even three steps and at the same time to increase the brightness ceiling with 2-3 points compared to what it used before.

In the 90's it was common to fully bleach the pulp with 6 or even 7 bleaching stages as in the following sequences:

- A-ZD-Eop-ZD-Ep in Pietarsaari (Finland),
- Q-OP-D-Z-PO-P in Blankenstein (Germany),
- A-ZD-Eo-DnD in Espanola (Canada).

Bleaching sequences built in the last decade for both hardwood and softwood pulps usually have only 3 or 4 stages and do not much vary from one another:

- Z-D-Ep-D at Nippon Paper Yufutsu (Japan);
- ZEop-D-P at Mondi Ruzomberok (Slovakia);
- ZD-E-D at Nippon Paper Maryvale (Australia);
- Ze-DP at ITC Bhadrachalam (India);
- Z(EOP)-(PO) at Sniace (Spain, sulfite pulp for dissolving grades);
- Ze-D-P at Celtejo (Portugal)

These bleaching sequences reflect the continuous and impressive developments of ozone application in light-ECF bleaching process and clearly show the worldwide interest of pulp makers in ozone bleaching.

PERPECTIVES

Having improved pulp mixing technology and better understood pulp quality impact resulting from the rationalization in the ozone dosage, the advantages using ozone have been clearly demonstrated at industrial scale. However, the story is not completely finished.

The coming step is the implementation of "Green bleaching" practices [25] where the usage of chlorine chemicals such as chlorine dioxide usage is minimized or even completely eliminated. As explained before, when hardwood pulp bleaching is concerned and for Eucalyptus pulp in particular, it is known that ozone is considered as an efficient HexA removal agent. However for economical reasons, a significant part of the job can be efficiently done by an A-stage. In that case, the use of ozone could be mainly focussed on both finalizing pulp delignification and starting final pulp brightening. The ozone stage is moved downstream of the bleaching sequence. After OO-A bleaching steps, the incoming kappa number in the ozone stage should be in the range of 5-6 units. One can argue that high temperature could remain a limiting factor in the ozone application especially when located after an A-stage generally performed at high temperature. However, it has been shown that high temperature (80°C) in the ozone stage is not a limitation but, on the contrary, is beneficial since it increases sensitivity of the coloured groups (chromophores) remaining into the pulp toward ozone oxidation [26]. In such a process the ozone dosage should be limited in the range of 1 to 3 kg per ton of pulp and, ozone charge can be split to maximize efficiency. Thanks to its very low capital investment cost, medium consistency ozone mixing technology should be the preferred choice.

The final objective is to definitively eliminate chlorine chemistry and to implement a bleaching chemistry only based on oxygen, peroxide and ozone. Bleaching options such as OO-A-Op-ZP or OO-A-ZP-ZP are investigated to find the best compromise to compete against modern ECF bleaching. The expected advantages of that such "Green Bleaching" alternative will be:

- Limited capital investment cost with MC ozone stages using compact equipment (minutes of retention time) easy to integrate.
- Low operating cost since bleaching efficiency of ozone is at least 3 times higher than chlorine dioxide when ozone is used in the middle/end of the bleaching sequence [6].
- Low carbon footprint emission since the main chemicals are produced on site (oxygen & ozone) limiting transportation, storage of chemical precursors [25].
- No risk of hazardous by-products formation such as Dioxins & Furans which could be potentially generated during modern chlorine dioxide generation technology [27]. On the contrary, the single by-product of ozone is oxygen that can be further valorised.
- Possibility of high level of water closure and limited water usage if needed
- Equivalent pulp quality when compared to ECF.

CONCLUSIONS

Ozone bleaching has already been industrially implemented, experienced and improved from the past 19 years. It is a well proven and safe process, currently used by some reference pulp mills among the most modern in the world. It has advantages in terms of bleaching cost savings, effluent load reduction and usage simplicity. It is applicable to all kind of pulps and has no negative impact on their mechanical properties when the process design is correctly performed.

As a result of continuous improvements of the equipment and process automation as well as tuning of the operating conditions for almost 20 years, modern ozone bleaching is recognized today as a state of the art technology for both hardwood and softwood pulps.

Risk and cost remain the main criteria of the decision making process in every project. ECF is still considered today as the Best Available Technology but when the discussion is based on arguments against arguments regarding cost, pulp quality and environment, and is not driven by other interests, it can be easily demonstrated that ECF is more expensive and has already reached its "ecological terminus". On the contrary, "Green Bleaching" not only answering to the today's requirement but also prepares the mill for the future. If, in 5 years, water usage or effluent emission or chemicals transportation and storage will become critical factors, the mills having already adopted "Green Bleaching" practice will be in a better position to maintain profitability. If the pulp mill has finally the same pulp quality and lower operating cost, such a change is becoming irresistible.
All technologies protecting environment and biodiversity should be promoted from a long term perspective.

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