# PERFORMANCE PARAMETERS OF OXYGEN DELIGNIFICATION

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***OXYGEN DELIGNIFICATION AS A KRAFT FIBER LINE COMPONENT HAS GROWN DRAMATICALLY IN THE PAST 25 YEARS. THE AUTHORS PRESENT CURRENT PERFORMANCE DATA FOR THE OXYGEN DELIGNIFICATION SYSTEM FOR 78 DIFFERENT BLEACHED KRAFT PULP LINES AROUND THE WORLD.***

We have collected current performance data for the oxygen delignification system at 78 different bleached kraft pulp lines globally. Key operating parameters show that levels of delignification vary from 28% to 67% for softwood and from 29% to 55% for hardwood. The averages are 47% and 40%, respectively.

Analyses of the data include the type of cooking, incoming kappa number of pulp, consistency level, number of stages, and other variables. The analysis shows there is no common factor related to performance. Operation is a mill specific target. Post oxygen stage kappa numbers reported level out at a minimum of 10 for softwoods and 8 for hardwoods.

We review the dramatic growth of oxygen delignification as a kraft fiber line component over the last 25 years. We also show the geographical distribution of systems and review the reasons for growth. There are examples of one- and two-stage systems.

The data presented uses operating information from individual mill systems. Sometimes, a mill system has been counted twice as it swings from softwood to hardwood operation. The data comes from internal company files, published and unpublished literature, supplier files, and private communications. We have usually verified that the information in the database represents the current operation of the system. Individual systems have only a code number, but they represent all the major regions of the world.

## CURRENT STATUS

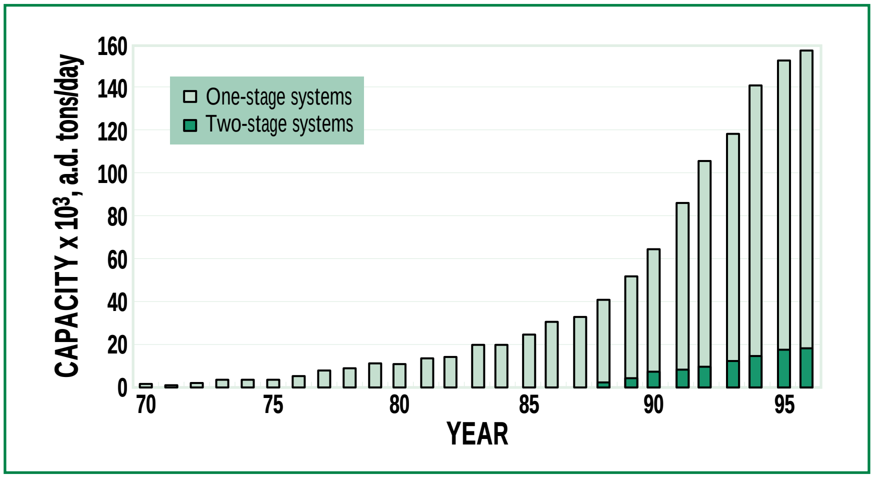
At the beginning of 1970, no full-scale, commercial oxygen delignification systems were operating. In 1996, almost 160,000 daily tons of the world's bleached kraft pulp production passed through an oxygen delignification stage. **Figure 1** shows that 80% of these installations have come on-line in the last 10 years since the development of medium-consistency, high-intensity mixers. Half of the total are as recent as the last five years.

It is reasonable to expect that there will always be a situation where a mill will decide it cannot justify adding oxygen delignification. It usually appears as an automatic inclusion in a new mill. Most existing mills will eventually retrofit an oxygen delignification system. How fast this will happen depends on various considerations including environmental pressures, market demands, capital availability, recovery boiler and chlorine dioxide plant capacity, and new technical developments.

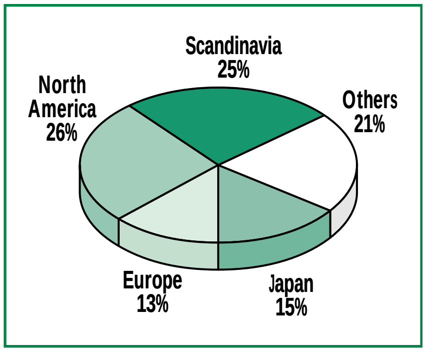
The incentive to install oxygen delignification has changed over the years. In the early 1970s, driving forces came from a need to close the washing and screening system to reduce chemical costs. There was also the demand to reduce effluent BOD and color. This led to early popularity in Sweden with reduced bleach effluent loading to deferring the capital and operating cost of secondary effluent treatment with bleach chemical operating cost savings.

Now environmental regulations for dioxins, AOX, color, and COD exist. Many mills previously meeting BOD discharge requirements with secondary treatment systems found that oxygen delignification was a convenient means of meeting these new targets. As an additional incentive, there is the operating cost saving to offset at least some capital cost incurred.

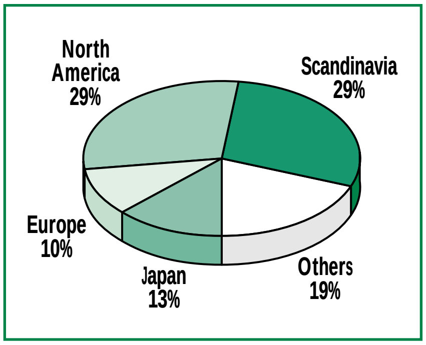
Today dioxin levels are no longer an issue, but regulatory authorities continue to require lower and lower AOX, color, and COD discharge levels. Other major pres-




*1. Worldwide production capacity of oxygen delignified pulp*




*2. World distribution of oxygen delignification installations*




*3. World distribution of oxygen delignification production*

sures come from an environmental demand for elemental chlorine free (ECF) and a significant market demand for totally chlorine free (TCF) pulps. Some mills are producing ECF pulps without oxygen delignification but paying a premium for bleach chemicals. Other oxygen delignification systems have been installed as alternatives to new, larger chlorine dioxide plants as a direct result of the move away from elemental chlorine and hypochlorite bleaching. Those mills producing or planning to produce TCF pulps with or without ozone need the low kappa number that oxygen delignification can provide to achieve an effective and economical bleaching operation.

**Figure 2** shows that Scandinavia and Europe together still have the largest number of installed systems in the world—approximately 38%. North America follows closely with 26%. In this chart, others include Asia, South America, and Australasia. It is important to recognize that the penetration is 100% for Sweden, almost 100% for both Norway and Finland, more than 80% for Japan, and less than 40% for North America.

In **Fig. 3**, the distribution of actual tonnage shows the numbers for Scandinavia and North America are essentially equal at 29% each. The reduction in the share of the actual tonnage for Europe and Japan is due to the number of smaller mills in those areas. The low percentage of total production currently using oxygen delignification in North America is changing with announcements of new installations. This change may increase depending on the outcome of pending legislation and some current developments in technology.

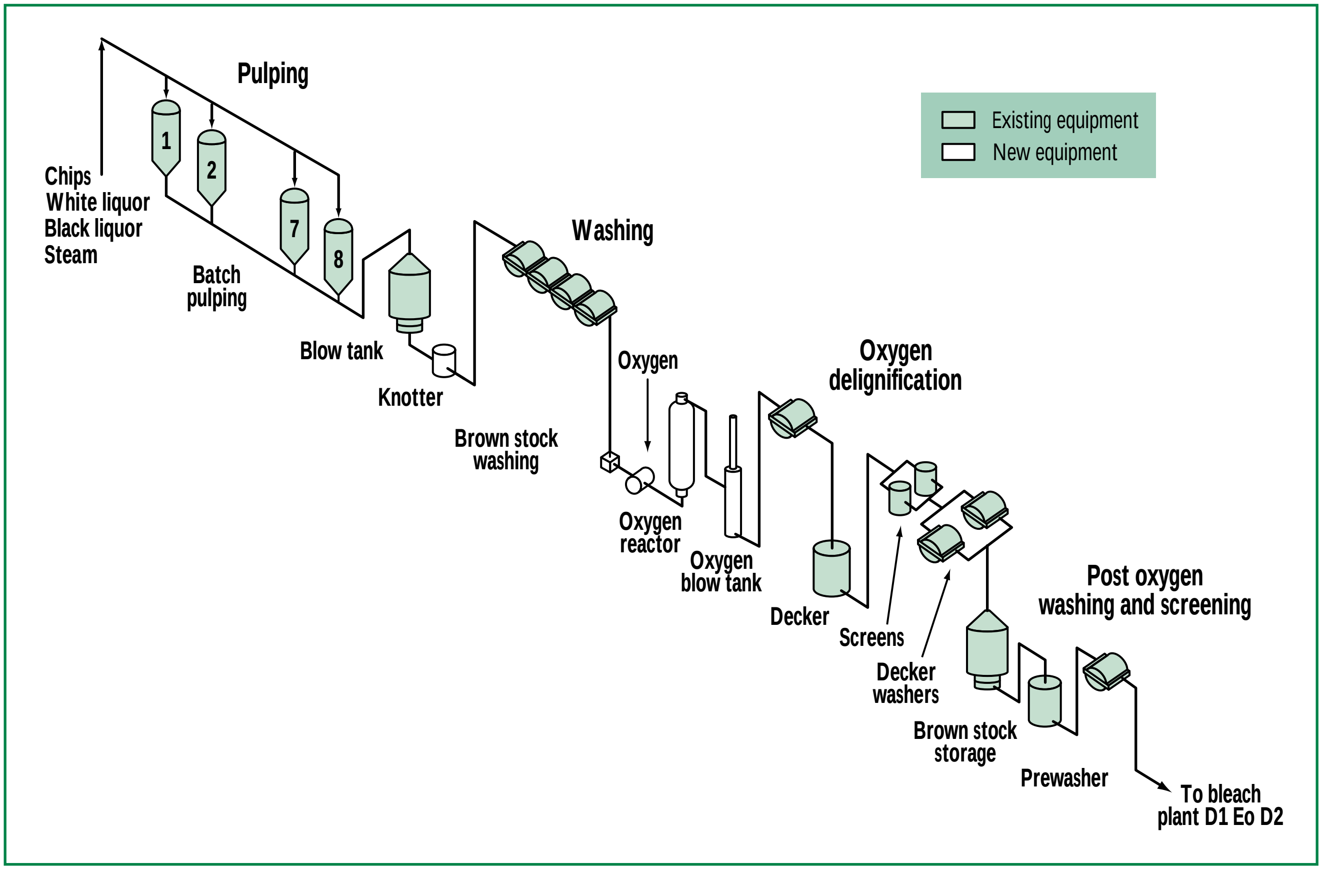
## INSTALLATION EXAMPLES

**Figure 4** shows an example of a one-stage oxygen delignification system for a hardwood line. It was apparently a simple retrofit that only required a feed pump, mixer, reactor, and blow tank. The mill was endowed with an abundance of washers available for use. In reality, a second fiber line was upgraded simultaneously. This made additional washers available. Note that this mill elected to leave the screens in the post oxygen location because the existing close-coupled, four stages of washing following the batch digester system were adequate ahead of the oxygen stage. Retrofits for oxygen delignification present as many different configurations as there are mills. This is because all mills are different or have different objectives.

With the continuing drive toward lower kappa numbers in the bleach plant, two-stage systems offer one solution. Figure 1 shows a steady increase in the number of these systems with a recent surge in activity. The flexibility and opportunity to adjust the individual stages to optimize strength and delignification and to adapt to future technology such as interstage activators will probably result in more two-stage installations.

Many two-stage systems are in this survey. They are at the higher end of delignification for both softwood and hardwood.

**Figure 5** shows an example of a two-stage oxygen system retrofit in a softwood pulp mill. This mill is unique because it elected to install an interstage washer and two new post oxygen washers. The database includes two




*4. One-stage oxygen delignification retrofit for 760 a.d. tons/day of hardwood*

systems with interstage washing. Both report better than 60% delignification. A third similar installation is not in the database because of a lack of sufficient data. Without the interstage washer, the only difference between one- and two-stage systems is the additional mixer and reactor. There can be several more variations in the configuration. Some mills pump between the two reactors to set the scene for other future modifications or interstage treatments as they progress from research and development to reality.

Reaction kinetics indicate a rapid first phase reaction followed by a slower second phase reaction. This should lead to two-stage design with a smaller first-stage reactor. In practice to date, most two-stage systems have used equal-sized reactors. Retention times selected by the designers vary from 20 to 90 min per reactor.

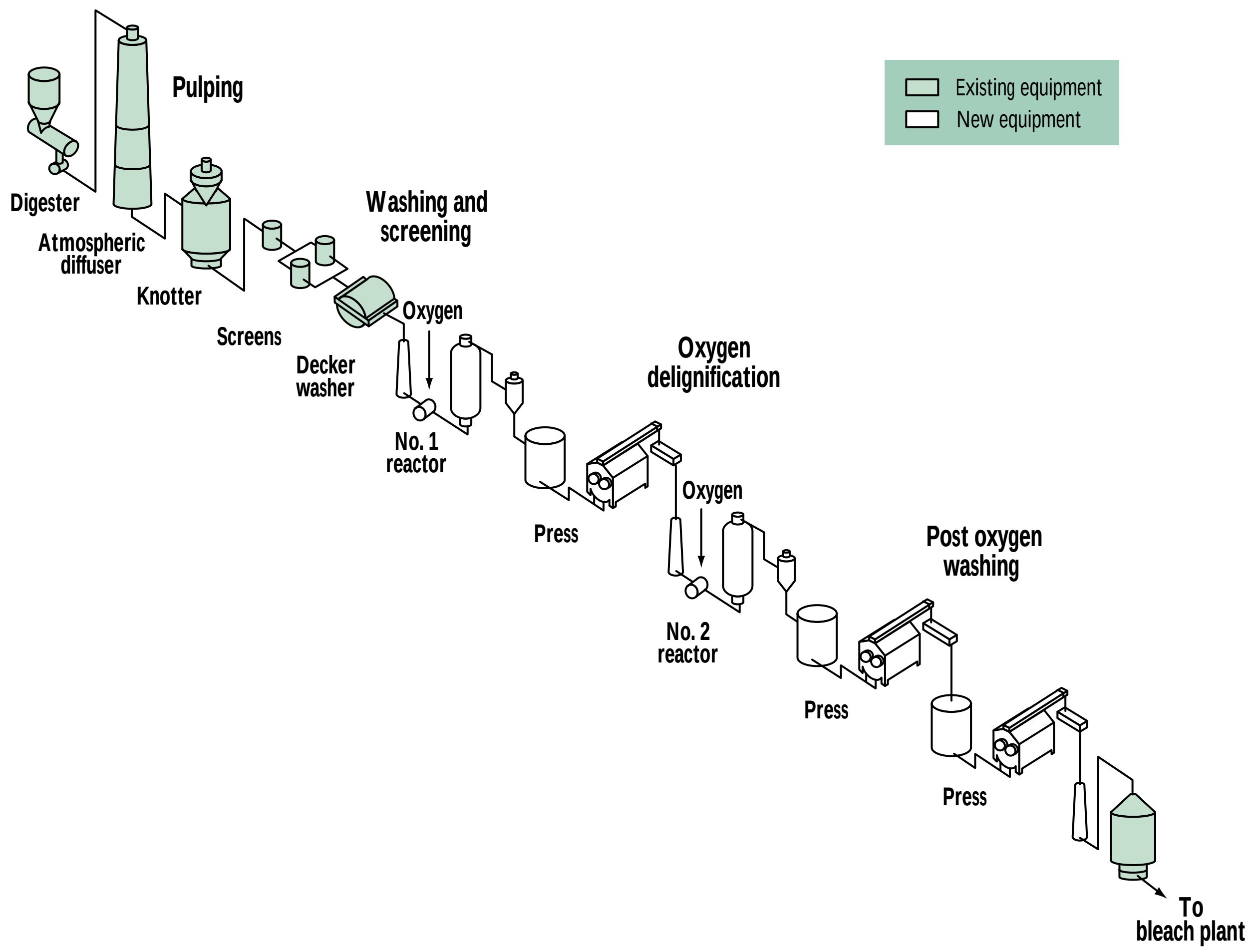
## OPERATING DATA

For all the mills reported in this study, the degree of delignification is the decrease between digester kappa number and post oxygen kappa number. Some mills are now monitoring the decrease across the brownstock system ahead of the oxygen stage. Reported data indicates that a decrease of 1–2 kappa units is quite normal. One mill reported a decrease of 4 kappa units. This leaching effect is most pronounced in the highly alkaline conditions between the digesting and oxygen stage. Several mills have located the high-density storage tower between the two post oxygen washers to maximize this effect by providing retention time for diffusion.

| | Total systems | Inlet kappa | Outlet kappa | Delignification, % |
|---|---|---|---|---|
| Softwood 1995 | 18 | 26.4 | 15.7 | 40.4 |
| Softwood 1996 | 43 | 26.3 | 13.7 | 47.5 |
| Hardwood 1995 | 12 | 15.9 | 9.9 | 37.7 |
| Hardwood 1996 | 35 | 17.2 | 10.2 | 40.2 |

*I. Data base performance change over one year*

The mills included in the database used to prepare this paper have installed systems supplied by all four primary vendors. The distribution between the vendors is evenly balanced. Although data is not present here, we can state from an analysis that the average level of delignification achieved—excluding high consistency systems—does not favor any particular vendor. The average




*5. Two-stage oxygen delignification retrofit for 700 a.d. tons/day of softwood*

| | High consistency | Medium consistency, one-stage | Medium consistency, two-stage |
|---|---|---|---|
| Softwood 1995 | 1 | 12 | 5 |
| Softwood 1996 | 6 | 24 | 13 |
| Hardwood 1995 | 0 | 10 | 2 |
| Hardwood 1996 | 2 | 22 | 11 |

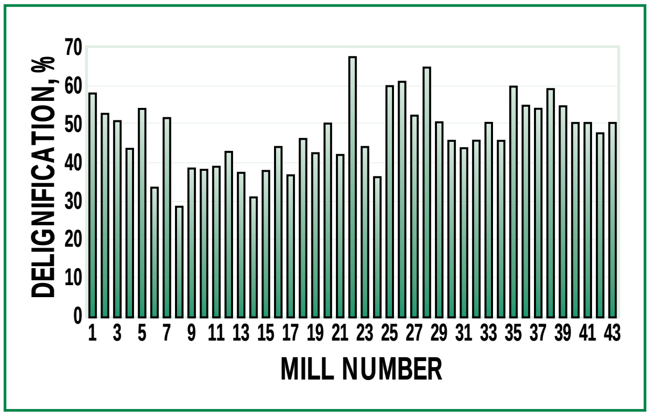
*II. Data base profile change over one year*

| | Average | Range |
|---|---|---|
| Inlet kappa number | 26.4 | 16–35 |
| Discharge kappa number | 13.7 | 8–20 |
| Delignification, % | 47.5 | 28–67 |

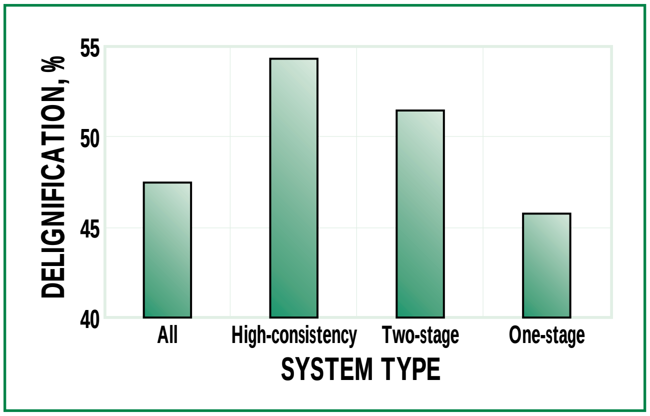
*III. Softwood pulps summary*

for each vendor is very similar to the averages presented below.

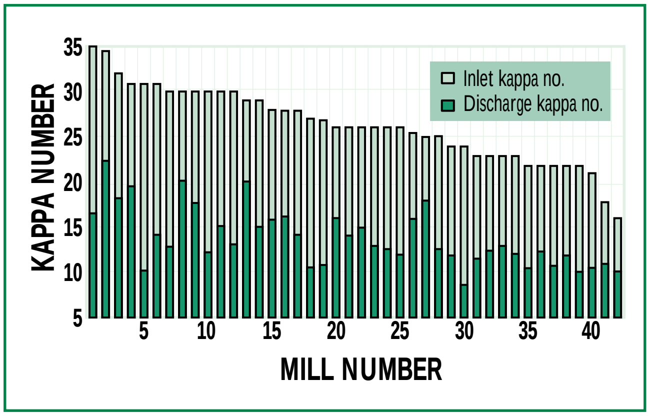
Data collection began more than one year ago with an original report at an American Institute of Chemical Engineers meeting associated with the TAPPI 1995 Pulping Conference. That data covered 30 systems. Now the information represents 78 systems and covers a geographical spread including North and South America, Scandinavia, Asia, and Australasia. **Table I** shows the changes in key performance parameters from this increase in the database. Performance of hardwood systems has only changed moderately. This is primarily due to an increase in average incoming kappa number. A large increase in the average delignification for softwoods has occurred. The primary reason for this change is shown in **Table II**. The table shows that for the 25 sets of softwood data added, five are for high consistency systems and eight are for two-stage systems. These 13 systems all report high delignification levels.



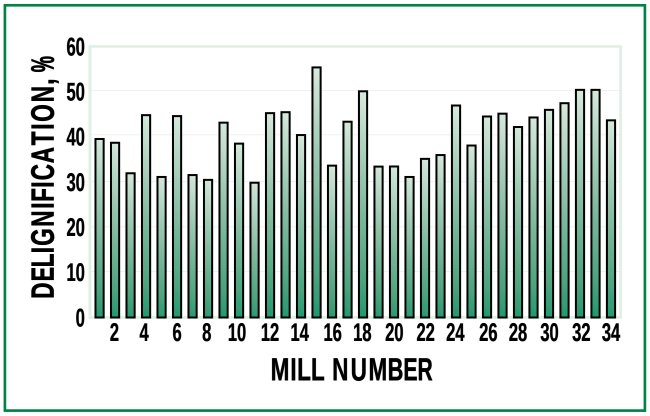

***6. Performance database for softwoods by mill***




***7. Performance database for softwood systems by type***




***8. Peformance database for softwoods showing kappa number reduction***




***9. Performance database for hardwoods by mill***

## SOFTWOOD OPERATIONS

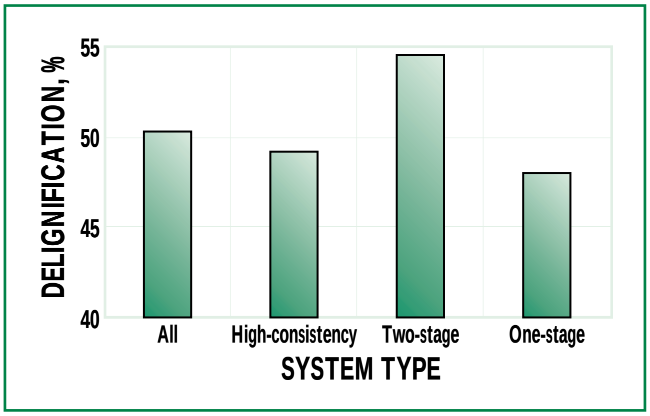
**Figure 6** presents the data for 43 softwood operations. It shows an average delignification of 47.5%. A wide variation exists between the lowest delignification at 28% and the highest at 67%. We have analyzed many factors to find a reason for this variation.

We grouped the systems by type: high consistency, two-stage, and one- stage medium consistency. An analysis in **Fig. 7** using average performance by type of system clearly indicates that high consistency systems have the best performance at 54%. Following this are the two-stage medium consistency systems at 51%. The one-stage medium consistency systems are least effective at 46%. It is possible that the better performance of the high consistency systems results from better washing before the oxygen stage because of the inclusion of a feed press.

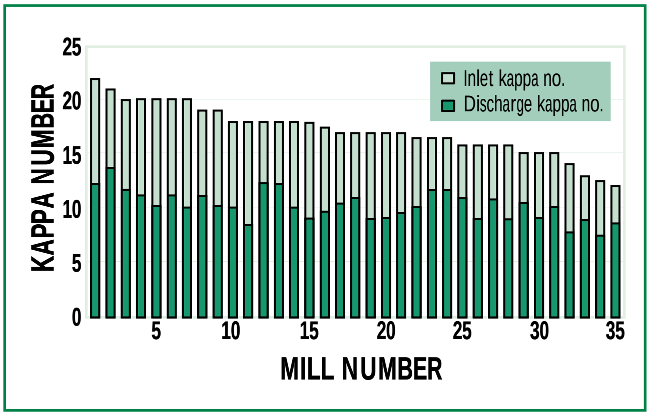
To look at the oxygen stage performance related to digester kappa number, we plotted the systems by descending inlet kappa number. **Figure 8** shows a range of digester kappa number from a high of 35 to a low of 16. Very little correlation exists to the degree of delignification in the following oxygen stage. The most noticeable statistic from this plot is a lower limit for softwoods of kappa number to the bleach plant at approximately 10 whatever the incoming kappa value. One mill in the database reported a kappa number of 8.5, and several other mills not included consistently operate below 10. A reasonable conclusion to draw now is that this is the limit at which the mills are comfortable with final strength properties.

The cooking performance of the digesting systems of these mills is not the subject of this review. It is interesting that those mills that are cooking to lower kappa numbers are also more consistent in driving the oxygen delignification harder and achieving lower kappa numbers to the bleach plant.

For softwoods, the summary shown in **Table III** gives an average of 47.5% delignification. It ranges from a low of 28% to a high of 67%. Although the variation in performance is high, only nine of the 43 systems are operating below 40% delignification. Of those nine, two have very low digester kappa numbers. The incoming kappa




*10. Performance database for hardwood systems by type*




*11. Performance database for hardwoods showing kappa number reduction*

| | Average | Range |
|---|---|---|
| Inlet kappa number | 17.2 | 12–22 |
| Discharge kappa number | 10.2 | 8–12 |
| Delignification, % | 40.2 | 29–55 |

*IV. Hardwood pulps summary*

number—ignoring the extremes—to the oxygen stage ranges from 32 to 22. This variation is the same in the outgoing kappa number range of 22 to 8.5 to the bleach plant.

## HARDWOOD OPERATIONS

This study includes data from 35 hardwood systems. **Figure 9** shows that delignification varies from a low of 29% to a high of 55% with an average of 40.2%.

Like the softwood systems, we grouped the performance according to the type of system. As **Fig. 10** shows, the two-stage medium consistency units outperformed the one-stage systems at 44.6% and 38.1% delignification, respectively. This difference of 6.5% is almost the same margin as that for the softwood systems. Since there are only two high consistency systems included, they are not representative.

**Figure 11** shows the plot of delignification in descending order of digester kappa number. Compared with softwoods, the kappa number leaving the oxygen stage has much less variation. It ranges from 7.6 to 13.5 with 85% of the systems reporting in the 9–12 kappa number range. Some cooking operations are achieving digester kappa numbers similar to oxygen stage discharge kappa numbers for other systems. Like the softwood data, this data appears to indicate a lower limit to post oxygen kappa number of 7.5–9 for hardwoods whatever incoming kappa number.

Note that digester kappa number targets for optimum yield and paper properties vary significantly depending on the hardwood species. For example, birch is often cooked to 18–20 kappa number. Many eucalypt species are being cooked to 12–14 kappa number.

**Table IV** shows a summary of the data for hardwood operations. The average level of delignification for the oxygen stage is 40.2% ranging from a low of 30% to a high of 55%. Kappa number variation is significantly reduced across the oxygen stage from a range of 22–12 at the inlet to 13.5–7.5 at the discharge.

## CONTRIBUTING FACTORS

The information collected in this database shows there is a large spread in the performance of oxygen delignification systems between different mills. We analyzed many parameters to find reasons for this variation. The type of system installed—high consistency and one-stage and two-stage medium consistency—appears to have an impact on the level of delignification achieved. Other parameters are more difficult to analyze and do not form trends. The following is a discussion of some factors that will influence operation of a given system.

### Digester kappa number

The digester kappa number varies widely from mill to mill. Based on a target kappa value into the bleach plant, it will affect the required or desired delignification in the oxygen stage. There is a trend toward raising digester kappa number targets and increasing oxygen delignification to maximize the total yield. This trend indicates there is an opportunity to increase the level of delignification in the oxygen stage without loss of strength.

Incoming kappa variation

If incoming kappa variation is significant, it will often cause a mill to ease off on oxygen stage performance and increase the work done by bleach chemicals to ensure an acceptable product.

**Insufficient controls**

This factor will make it difficult to handle incoming variations. Mills that have installed a good interactive control package—often with on-line kappa measurement—can achieve better results and cope better with incoming variations. The tendency to move to lower kappa numbers will also make supervisory control systems more important. Mills have reported reduction in the variation in discharge kappa number by up to 50% after implementing an enhanced control system.

**Pre-washing**

Pre-washing to achieve the optimum level of incoming black liquor solids is important to avoid limiting the kappa number drop because of strength loss. The leaching effect of residual cooking liquor and higher pH also put pressure on the need for good washing at this point in the process.

**Post-washing**

Post-washing must be sufficient to ensure that delignification is not curtailed to prevent excessive carry-over into the bleach plant. Post oxygen washing also affects the COD level circulating in the stage. This can impact delignification and pulp strength.

**Consistency**

The consistency of the pulp feed to a medium consistency oxygen stage requires control to avoid uneven pulp quality. To minimize channeling in the reactor, consistency should be above 10%.

**Pulp viscosity**

Pulp viscosity is often an indicator of pulp strength to limit kappa number in the bleach plant feed. Viscosity to strength relationships change after oxygen delignification and after extended cooking. The viscosity drop across the oxygen stage does not always translate into a strength drop in the bleached product. Each individual mill must ensure it is not penalizing itself because of a misleading quality parameter.

**Bleaching sequence**

This will impact the required level of delignification. For example, the mill could be running ECF with limited chlorine dioxide supply or running TCF with or without an ozone stage.

**Fiber source**

Combined with inherent basic fiber strength, fiber source can play a key role in the balance of delignification in the fiber line particularly in relation to the desired product.

## CONCLUSIONS

The study of the database collected for 35 hardwood and 43 softwood oxygen delignification systems provides some conclusions despite the wide variation in the performance of the systems. There is a clear indication that two-stage medium consistency oxygen delignification systems provide higher levels of delignification than one-stage systems. For softwoods, high consistency systems outperform medium consistency systems. The reason for this may be in the washing and not the actual oxygen stage.

There now seems to be a lower limit of kappa number into the bleach plant for softwoods of 9–10 and for hardwoods of 7.5–9. The analysis of the data collected to date does not provide specific reasons to explain the wide variation in performance between individual systems. Some factors listed above with sufficiently detailed information would probably provide further explanation of these variations. **TJ**

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