A new sensor and a novel control concept for optimized fiber line operation

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ABSTRACT: Kraft and sulfite pulp mills use several consecutive process stages for pulp production. However, usually only one key pulp parameter is used for process control and that is the lignin content in the fibers, typically expressed as the kappa number. Even so, to improve process efficiency, more variables need to be monitored. To do that, a new sensor was developed, the dissolved lignin transmitter (DLT), along with a new control concept. The DLT measures the dissolved lignin content in the pulp slurry using a unique principle based on optical measurements. The device can measure the dissolved lignin inline at low consistency and at medium consistency. The sensor has two major applications: 1) improving the efficiency in washing stages and 2) optimizing chemical charges. Results from several mill trials have shown that the contribution from dissolved lignin in the filtrate portion of the pulp is up to 30% of the total bleach load, i.e., fiber and filtrate kappa number combined into the bleach plant. Hence, chemical savings can be achieved taking this component into account compared to only measuring the washed fiber kappa number.

Application: The results of this study can help mills understand how to better control the pulping stages, which might lead to significant economic savings and better pollution control.

The process efficiency of a pulp mill is a complex function that depends on the pulp type, the pulp properties, the process equipment, and the conditions used. For the first process stages in an elemental chlorine free (ECF)-bleached kraft pulp mill (i.e., cooking, oxygen delignification, and the D_0 stage), the challenge is to achieve optimum delignification and high selectivity for obtaining low lignin content and high pulp yield and viscosity. A second challenge is to maximize the pulp production at the required final brightness and strength level.

The impact of operating cooking and oxygen delignification stages properly is well documented [1-4]. Operating too far from desired working points can result in significant loss of productivity, as through decreased yield and viscosity, though sometimes it is difficult to determine this directly and quantitatively. From a process control point of view, disturbance factors will contribute to process variability and result in offsets from the target set-points. Such disturbance factors may be related to the raw material (such as chip moisture, liquor strengths, wood composition, etc.). Disturbance also might result from inaccurate or improper process sensors being used (e.g., consistency, flow velocity, pH, etc.). Not every single property and constituent can be measured in every process stage. The inherent challenge is to identify the key process parameters to measure and base process control solutions on those parameters to achieve high productivity.

The degraded and dissolved lignin residues will ultimately go to the recovery boiler. However some downstream "leakage" -- black liquor carryover -- will naturally occur. Furthermore, even though the majority of the delignification occurs in the cooking stage, a significant reduction in kappa number takes place in subsequent stages, and this will add more dissolved lignin to the process streams.

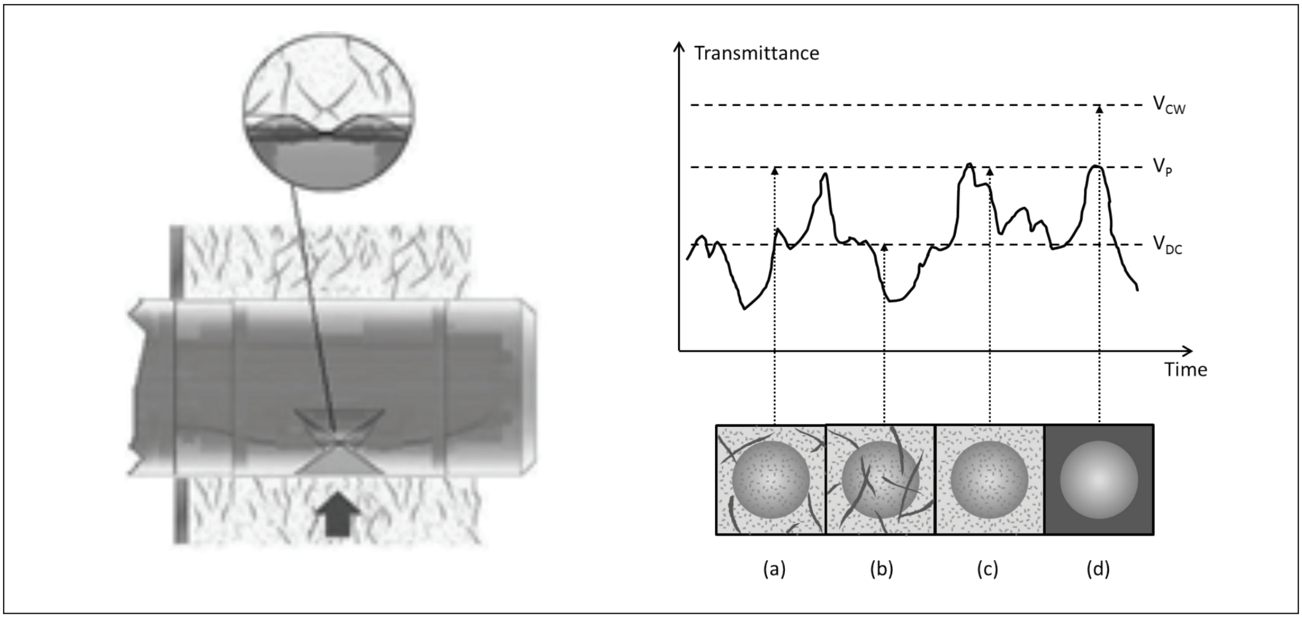
This paper describes laboratory and mill investigations using a novel sensing technology for determining the dissolved lignin concentration in various positions in the fiber line. Data are presented showing that the dissolved lignin's impact may be highly significant, and thus qualify as key input for automatic process control.

The composition of this black liquor carryover (organic and inorganic constituents) is well known, and sensor technologies now in use try to capture the carryover. However, they do not specifically measure the dissolved lignin content, which has been identified as being the most critical parameter in pulp washing, but rather the content of inorganic matter in the black liquor [5,6].

EXPERIMENTAL

Inline dissolved lignin measurement

The strong light absorption of the lignin molecule in the ultraviolet and visible (UV-VIS) light region because of its aromatic structure is well known. Current technologies use that light absorption for automatic fiber lignin content measurement, typically expressed as kappa number. It can also be used for determination of dissolved lignin by light transmittance measurement. However, such a measurement can only be performed on a filtrate (i.e., without fibers), and thus can only be conducted on a pure filtrate stream where the fibers have been filtered off [7].



1. Probe with measuring gap (left) and principle signal extraction (right) of the new sensor.

In contrast, our sensor for measurement of the concentration of dissolved lignin uses a unique principle capable of resolving the filtrate's light absorbance in the presence of pulp fibers. As shown in **Fig. 1**, when using a small measuring volume, defined by the 1.5 mm measuring gap, the periods corresponding to measurement of only the filtrate portion can be identified and used to calculate the light transmittance and absorbance, and subsequently to determine the dissolved lignin concentration. Figure 1 shows a typical transmitted light signal in a pulp slurry. Four situations (a-d) are shown to describe the principle and how the narrow light beam is affected depending on the conditions:

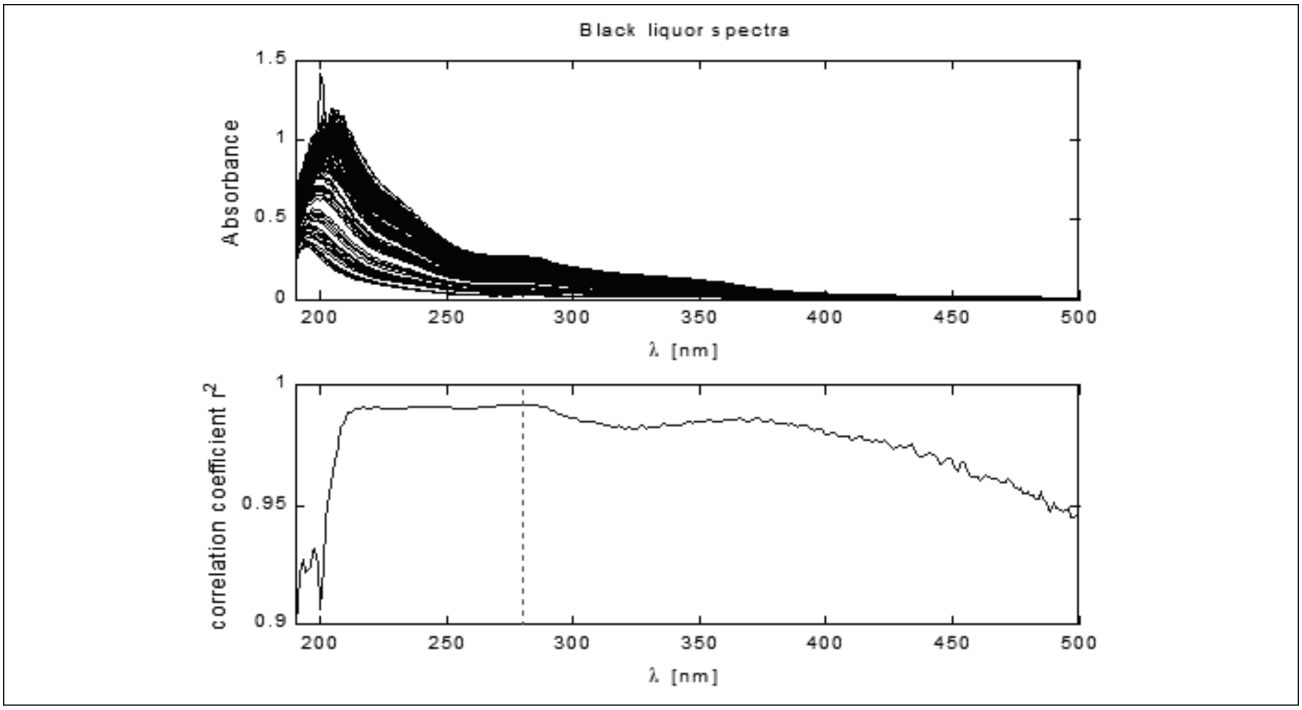
a) shows how the light beam passes through the pulp slurry in a moment without any fibers affecting, which means there is only filtrate in the measuring gap, V_P
b) shows the situation when fibers and filtrate are both present in the gap, V_{DC}
c) shows the situation when measuring in a filtrate without fibers, which gives the same signal as situation (a), V_P
d) shows the situation when the measurement is done in pure water, which gives the highest signal, V_{CW}

A common understanding is that determination of lignin must be performed in the UV region, and preferably at 280 nm. Because of the strong absorption of the lignin, most filtrates in a fiber line would have to be heavily diluted, or one would have to use an extremely short – and impractical – light path length, to achieve a measurable light throughput. However, the high correlation between the dissolved lignin concentration and the absorbance remains at higher wavelengths, where the magnitude of the absorption is significantly lower but still very dominant, and thus suitable for quantitative determination (**Fig. 2**) [8]. Note that the samples were diluted 1:1000 before the analysis in a measurement performed using a laboratory spectrometer and a 10 mm cuvette. Subsequently, the wavelength used can be selected to give a desired absorbance range depending on the concentration of dissolved lignin in the pulp.

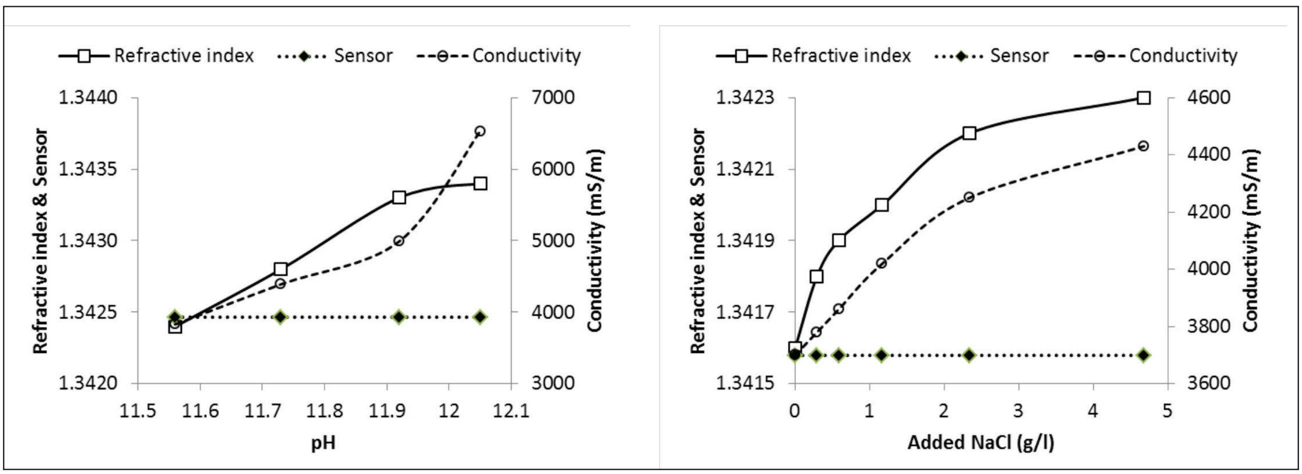
Under the assumption that the absorbance measured by the new sensor is directly related to the dissolved lignin concentration, no calibration is required except, for example, for scaling into filtrate kappa number. In that case, only one reference sample is needed. Assuming that the chemical oxygen demand (COD) correlates with the dissolved lignin concentration, one can also choose scaling into COD output, again using only one reference (COD) sample. Hence, the sensor is ready for use immediately after installation.

Filtrate kappa number measurement

The filtrate kappa number has been used as a measure of the concentration of dissolved lignin of the filtrates. This parameter has been used for calibration and follow-up of the performance of the new sensor. The filtrate kappa number method is very similar to the standard (fiber) kappa number methods of TAPPI T 236 "Kappa number of pulp" and SCAN-C1 "Kappa number," but uses a certain volume of filtrate as the basis, and thus provides filtrate kappa number per milliliter of filtrate (compared with kappa number per gram of fiber). To relate to the fiber kappa number, and to calculate the total kappa number (fiber + filtrate kappa number), the consistency of the pulp is used for combining the two numbers. In a pulp slurry going to an ECF bleach plant, the total kappa number corresponds to the total bleach load. However, this assumes that the permanganate consumption is a relevant measure of the remaining bleaching chemical demand for the fibers and the filtrates.



2. Upper: Black liquor spectra (absorbance) versus wavelength (nm), diluted 1:1000. Lower: Correlation coefficient r_2 *for the absorbance and lignin concentration relation versus wavelength (nm). The commonly used 280 nm is indicated with a dotted line [8].*



3. Effect of pH (left) and addition of sodium chloride (right) to mill pulp samples, on refractive index, the new sensor, and conductivity.

RESULTS AND DISCUSSION

This work focused on mill studies, along with some basic laboratory trials, to verify some basic principles and to understand the characteristics compared with current technologies used in mill applications.

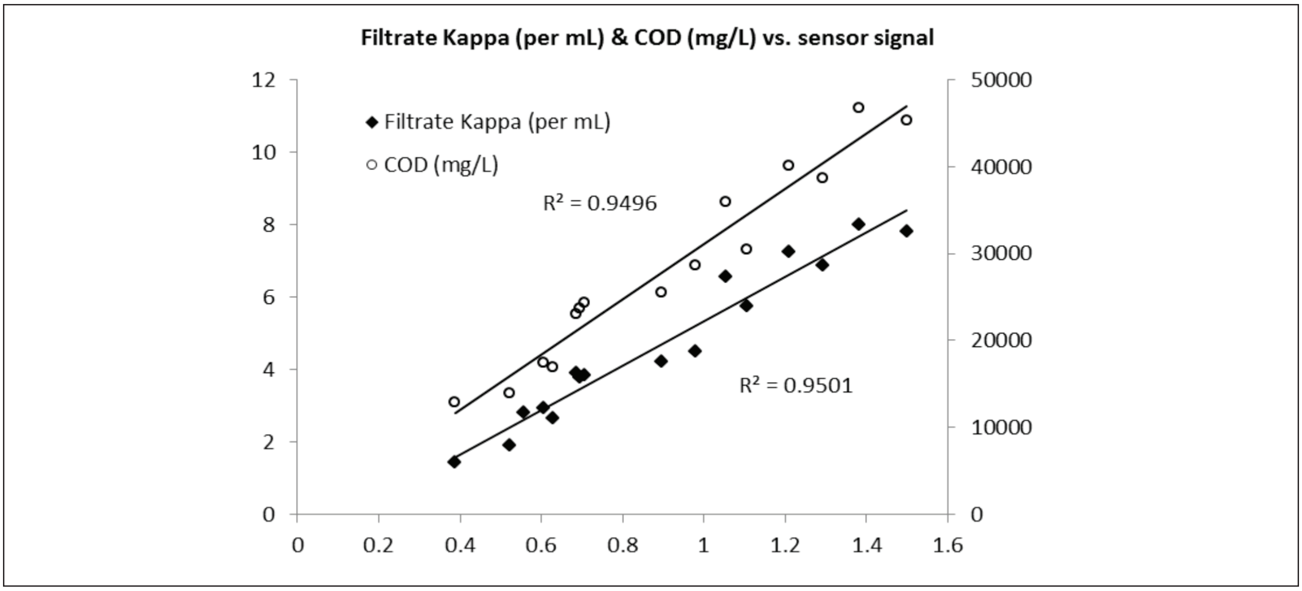
Laboratory investigations

To understand how currently used technologies are affected by the content of inorganic matter in the studied black liquors, the sodium hydroxide and sodium chloride concentrations in mill filtrate samples were modified.

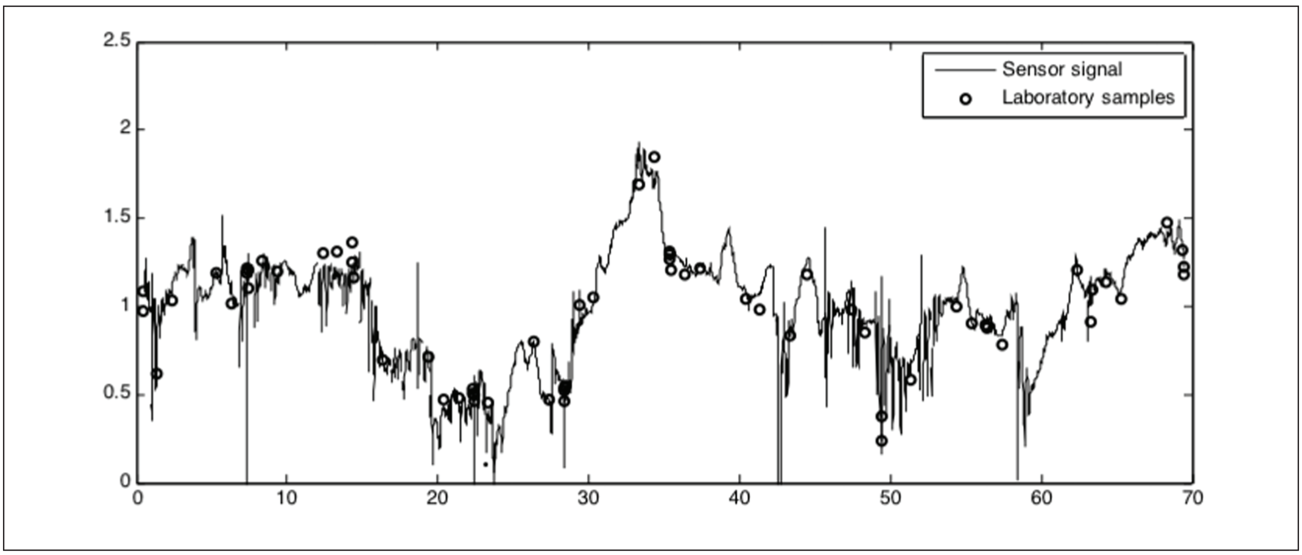
Figure 3 shows that the conductivity and refractive index are significantly dependent on the chemical additions. It should be noted regarding the scale for the refractive index that very small absolute changes occur in general, and a difference of only 0.0010 units corresponds to as much as 3.0 filtrate kappa units in the position from which the liquor was taken. The new sensor for dissolved lignin, as expected, was practically unaffected by the chemical additions (Fig. 3). The sensor signal is normalized to be plotted together with the refractive index and conductivity.

Mill investigations

The sensor has been installed in several pulp mills and in different positions, as described in the following two examples.



4. Filtrate kappa number (per milliliter, filled symbols, left axis) and chemical oxygen demand (mg/L, circles, right axis) versus the new sensor signal. Data from mill case 1.



5. A 70 days trend of the new sensor's scaled output signal and laboratory determined filtrate kappa number samples (per mL filtrate). Data from mill case 2.

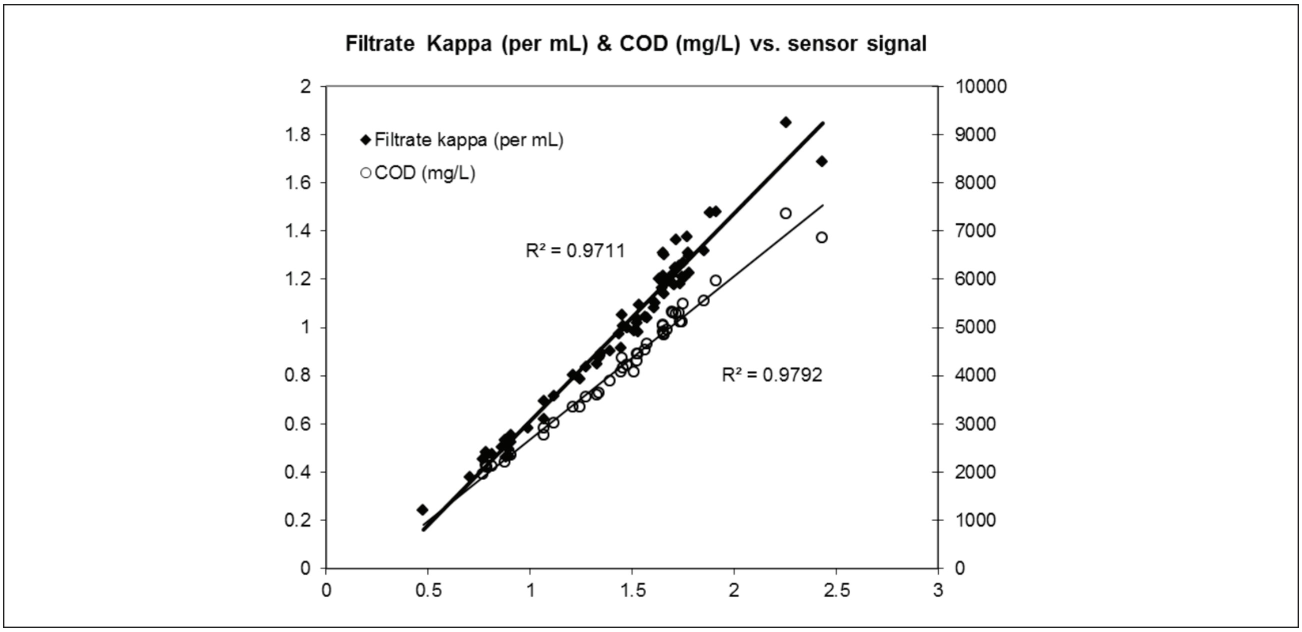
Case 1. Brownstock washing control

This softwood sulfite pulp mill has nine batch digesters that feed a single blow tank. Depending on the pulp grade, the digesters yield 18-24 batches per day, over a large kappa number range. The level in the blow tank fluctuates significantly because of the constant discharge flow rate and the irregular inflow of pulp from the digesters. Pulp is pumped from the blow tank to a horizontal belt washer. The consistency of this pulp feed is controlled by a consistency controller that manipulates the flow of dilution water.

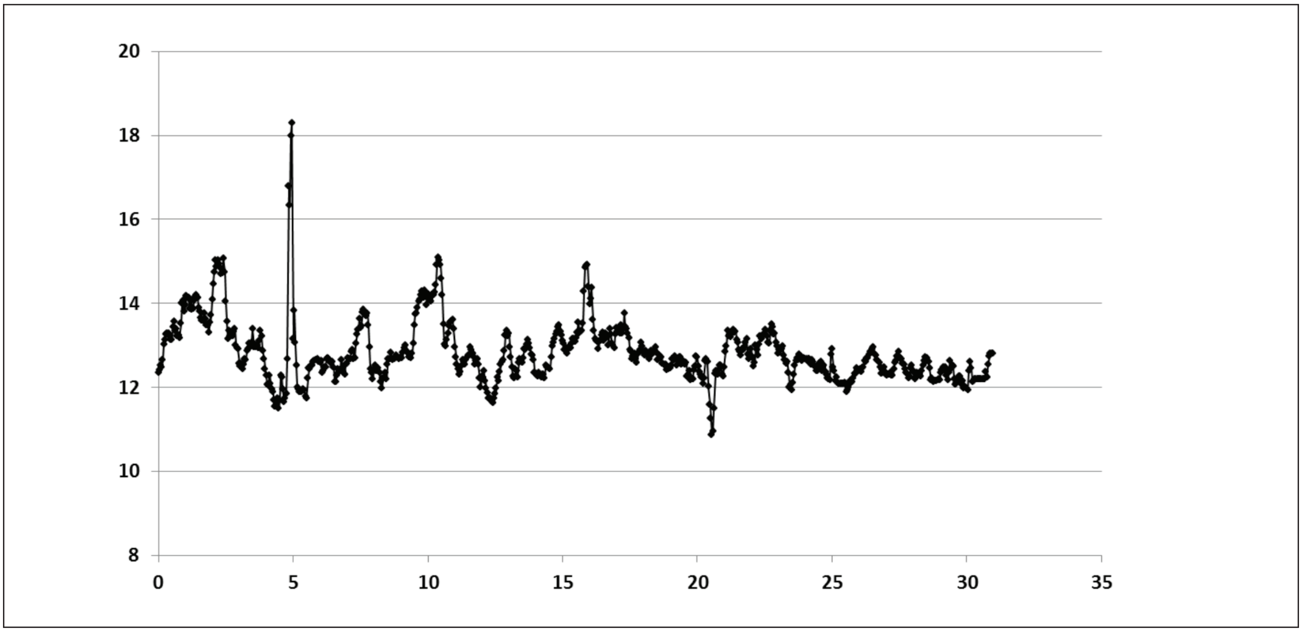
Figure 4 shows the filtrate kappa number versus the corresponding sensor signal from a brownstock washing mill trial. It shows a good linear correlation between the sensor signal and the filtrate kappa number. Thus, it is possible for the pulp mill to regularly obtain information on the concentration of dissolved lignin in the pulp slurry. The correct dilution factor in this fiber line position can be calculated by combining the concentration information with the liquor volume per ton of pulp and the production rate.

Figure 4 also shows COD versus the sensor signal for the same fiber line position. This case also shows a good linear correlation. Thus, it is possible to replace the tedious, costly, and environmentally problematic COD test with the signal from the new dissolved lignin sensor.

The mill uses the value of the dissolved lignin content to control the wash water applied to the brownstock washing



6. Filtrate kappa number (per mL, filled symbols, left axis) and chemical oxygen demand (mg/L, circles, right axis) versus the sensor signal. Data from mill case 2.



7. Pre-D_0 fiber kappa number versus time (days), indicating typical variability. Data from mill case 2.

system. The dissolved lignin value is also indicative of a certain final product specification. This information allowed the mill to maintain final product specifications for numerous grades of pulp produced at the mill and to optimize the liquor solids to the spent liquor recovery system [9].

Case 2. Feed to bleach carryover measurement

In this case, the sensor was installed before a wash press before the D_0 stage of a softwood kraft pulp mill. Pulp consistency at this location was 4%-5%. **Figure 5** trends the sensor output during a period of 70 days, scaled to filtrate kappa number, along with laboratory reference data (69 samples). The fit between the sensor trend and the reference data is very good. This is also seen in **Fig. 6**, which shows the filtrate kappa number and COD versus the sensor's raw signal, both with correlation coefficients r^2 above 0.97. The variability of the dissolved lignin concentration is also quite remarkable. Assuming an average pulp consistency of 4.5% and a filtrate density of 1 g/mL, one filtrate kappa number unit (i.e., per milliliter filtrate) corresponds approximately to a kappa number of 21 on fiber basis (i.e., even more than the fiber kappa indicated in Fig. 7). This is, however, before the wash press; the filtrate kappa contribution will be lower after the wash press.

A sensor was also installed after the wash press of the D_0 stage, where the inlet pulp consistency was 8%-10%. The filtrate kappa number on a series of laboratory samples taken during approximately one month varied between 0.06 and 0.23, with an average of 0.16 (per milliliter). At 9% consistency, this corresponds to an average of 1.6 kappa number units on a fiber basis (i.e., approximately 10% of the total kappa or bleach load). However, the variability of the filtrate kappa number corresponds to approximately +/-1 kappa number unit (on fiber basis), which must be considered significant relative to the fiber kappa variability. Based on data for fiber kappa number variability in this position, approximately 1/3 of the total bleach load variability originates from the filtrate kappa number variability (i.e., carryover), and subsequently, approximately 2/3 from the fiber kappa number variability (Fig. 7).

Practical implications and scope of further studies

In a third trial, at a pulp mill producing bleached softwood kraft pulp, the sensor was installed in the inlet to a D_0 stage. In that pulp mill, the dissolved lignin content variations corresponded to more than 4-12 kappa number units (on fiber basis). This high variation in the filtrate kappa number clearly exceeds the variability of the washed fiber kappa number, which was between 12-15 kappa number units. The D_0 stage operated at low pulp consistency (~4%), which made the filtrate portion's impact on the total kappa number higher.

The conditions determined in a pre-oxygen (O_2) position in a fourth mill trial showed average filtrate kappa numbers of 7 and a range of 4-10 kappa number units per milliliter filtrate for laboratory samples. With 10% consistency, this filtrate kappa number corresponded to 63 kappa number units on fiber basis (range: 36-90). The target cooking kappa number is 30 at this mill.

The significant contribution of the filtrate kappa number

ABOUT THE AUTHORS

The international pulp and paper industry is under pressure to reduce costs and improve economic performance. At the same time, reduced pollution load has top priority. For chemical pulp mills in particular, the delignification process is critical. The current research was undertaken to investigate how improved process measurements can provide better means for optimization. Thus, a sensor for measurement of dissolved lignin, which is known to affect the processes, was developed and validated.

Optimization of washing operations is very important in the pulp mills because improved washing efficiency typically has short payback time. This explains why washing studies are frequently published in scientific papers, but there is a need for proper tools to be able to improve the situation in the mills.

The biggest challenge was to develop a sensor that was unaffected by pulp consistency variations. This was addressed by extensive trials both in the laboratory and in the mill environment.

The most interesting result of the work was the magnitude of the variations of the dissolved lignin concentration. In some mills, these were actually bigger than were the fiber kappa variations.

The results bring understanding about how to control the pulping stages better, which may have significant economic improvement for mills, and also provide a means for better pollution control.

Several further research activities are planned using the new sensor, such as to investigate in which positions the sensor should be installed to achieve an optimal control, and to create understanding about the underlying mechanisms of the reactions of the dissolved lignin. The direct economic impact will also be studied in further mill trials.

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to the total bleach load into the D_0 stage calls for understanding whether the filtrate kappa number itself provides a relevant measure of the bleach demand of the dissolved lignin. The reaction rate of the dissolved lignin compared with the fiber lignin is also of importance to fully understanding how to exploit the new sensor. The reactivity of the dissolved lignin might also play a role if, for instance, it is a recirculated oxidized filtrate.

The findings from studying the pre-O_2 position, where evidently most of the total kappa number (i.e., permanganate consuming compounds) is in the filtrate portion of the pulp, also requires further investigation.

CONCLUSIONS

The key conclusions based on the present study are as follows:

- An inline sensor for dissolved lignin, called DLT, has been validated in laboratory and mill trials in several mills and at positions from pre-O_2 to pre-D_0. The sensor's correlation with dissolved lignin measured as filtrate kappa number and COD was found to be very high.
- The sensor operates inline in the pulp stream. It is precalibrated and requires only one sample for scaling for desired output.
- Investigations using the sensor have revealed that the dissolved lignin in the filtrate is a significant share of the total kappa number and it contributes to a large part of the total variability thereof.
- The sensor can also be applied for washing control (i.e., for optimization of the use of wash water with respect to energy consumption in evaporation and pulp cleanliness). In a mill application, the sensor output is used as a valuable tool for modulation of dilution factor and the overall control of the brownstock washing system.
- The sensor can be applied for control of charging of bleach chemicals. Together with the fiber kappa number, the total bleach load can be calculated for optimizing process performance.
- According to the present findings, dissolved lignin is likely a key process parameter that until now could not be measured inline for control purposes. The new sensor for dissolved lignin opens up new opportunities for optimizing fiber line operation.

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