BLEACH PLANT CONTROL OPTIMIZATION USING INLINE BRIGHTNESS AND RESIDUAL MEASUREMENTS ALONG WITH ON-LINE KAPPA MEASUREMENTS

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ABSTRACT

While on-line optical Kappa measurement is now an established means to control brightness, the use of in-line brightness and residual measurements along with the kappa measurements enhances the control performance in Kraft bleaching. This combination along with a predictive and adaptive control algorithm provides an excellent strategy for mills targeting lower operating costs with higher pulp quality.

This paper describes how the economic benefits are consistently achieved at a mill in South America. The ClO₂ control model and the salient features of the model are discussed along with the measurement of on-line Kappa before the bleach plant and after the first extraction stage. Also the use of in-line brightness and residual meters after the bleach feed, first Extraction Stage, D1, and D2 stages of a four stage bleach plant are discussed. The bleach plant that will be discussed has the sequence of D0, Ep, D1, and D2. This paper will discuss how these on-line measurements are utilized along with in-line continuous measurements to control each bleaching stage. This paper will describe how the all the measurements are used for feed-forward controls when they are located on the inlet of the stage. It will also discuss how these same measurements are used for feedback correction when they are located on the outlet of the stage. The paper will also explore whether inline sensors are suitable for feedback controls and for replacing lab measurements as compared to an offline automatic analyzer that can be used for the same purpose.

Finally, the reasons why this model works well are explored. The reasons why bleach plant controls is so challenging is also explored, along with the reasons why well designed bleach plant control using the correct measurements is so important.
BLEACH PLANT CONTROL OPTIMIZATION

BACKGROUND

The bleach process area is very dynamic and there are many process variables that affect its operation. The challenge is to meet final brightness targets with minimal variation and without damaging any other pulp properties. The challenges associated with controlling this process area include the reliability of data, dynamic process parameter relationships, and long process delays. To add to that, the bleachability of the pulp is not always constant, the process is non-linear, sometimes errors are made in decision making and lab tests, and there are different running habits between shifts. These challenges make it impossible to implement simple static controls that are robust enough to handle a variety of process conditions.

In the bleach plant process, there are several variables to control on each bleaching stage. This paper will focus on the controls of an oxygen delignified four stage bleach plant with the Sequence of D0, Eop, D1, and D2. The primary process variables that affect each stage are the inlet kappa, brightness, bleachability, pH, carryover, temperature, consistency, chemical strengths, and the retention time. Each of these variables needs to be controlled as well as possible. When that is done well the bleach plant can be optimized to reduce the cost associated with increasing the brightness of the pulp and to provide high quality pulp to the either the paper machine or the pulp dryer. Whenever some of these variables are not already controlled well coming into the bleaching stage, the controls and measurements of that stage become much more important. Good measurements along with a good control scheme can help to overcome process disturbances that lead to some of these variables not being stable coming into the stage. This paper will focus on how the measurements and controls are designed to react to each of these variables coming into the bleaching stage at a modern mill in South America along with how the feedback controls influence the chemical dosages applied to each stage.
IMPORTANCE OF GOOD MEASUREMENTS

You cannot control what you cannot measure. This statement applies to any process area in a fiberline but is especially true in regards to the bleach plant. I mentioned nine variables that have varying degrees of influence on how a bleaching stage performs. The first two bleaching stages (D0 & Eop) function to delignify and brighten the stock. In a conventional bleach plant the primary function of these two stages was to delignify the pulp as much as possible. Delignify simply means to reduce the amount of lignin in the pulp. The lignin can be thought of as the glue that holds a tree together and is what provides the darker color to the pulp. The kappa # of the pulp is a measurement of how much lignin is in the pulp. In order to fully bleach the pulp all of the lignin must be removed. As opposed to a conventional bleach plant, an O2 delignified bleach plant has either one or two O2 stages preceding it. The O2 stage(s) reduces the lignin somewhere between 35 to 65% depending on the design of the stage(s) and on the pulp species. This means that there is much less lignin entering these two stages, so now much more brightening of the pulp can be done in these two stages. The primary variables that affect the amount of ClO2 that is needed to reach the Post-O2 Eop and brightness targets are the inlet kappa, carryover, and bleachability levels. A good control scheme should measure or infer these variables somehow and adjust the ClO2 dosage based on changing levels of these three variables. In order for these two stages to be efficient several other variables in the two stages need to be controlled also. The pH, temperature, consistency, and retention time need to be controlled to provide the maximum efficiency is both these stages.

CONTROLLING THE D0 STAGE

In the D0 stage the pH is typically controlled by measuring the inlet pH of the stage and adding sulfuric acid to bring the pH down to a level that ensures that the lignin is reduced as much as possible and allows the process to be free of scale as possible. It has been shown that lowering the temperature in the D0 stage can increase the delignification in the stage also. The ClO2 reaction with lignin is really fast, so lowering the temperature can help to slow the reaction and allow the ClO2 to stay in contact with the pulp fibers longer, which leads to increased delignification. However the temperature in the following stage needs to be much hotter, so there are limits as to how low of a temperature you can target. The retention time is normally fixed in the D0 stage since this is typically an upflow tower. If possible the consistency is increased to as high a level as possible. Increasing the stock consistency provides two benefits. The first being increased retention time in the stage and the second being that the chemical comes in
contact with the fiber more efficiently. At the mill discussed here, the consistency and temperature entering the bleach plant are controlled using standard PID control loops. The pH is controlled using an advanced control scheme where the filtrate pH is measured and targeted to a setpoint. This control loop then sets the setpoint to the inlet pH control loop. The inlet pH loop controls the acid dosage to hit the inlet pH setpoint. The ClO2 dosage is controlled in an advanced control scheme that utilizes many of the measurements of the bleach plant variables that I have mentioned. The primary measurement that determines the base level of the dosage target is the inlet kappa number from an online kappa analyzer. There are several other variables that can influence changing this base dosage though within set limits. An inline brightness probe is used to convert the online kappa measurement to a continuous kappa number. The brightness measurement is used between test to determine the direction and magnitude that the kappa # is changing between kappa tests from the online analyzer. The brightness probe is also used to compensate for any other changes in the process that are affecting the color of the pulp. As the brightness moves away from its normal level compared to the kappa #, this is indication that something has changed in the process. This could be changing due to higher brown stock carryover which indicates that the stock was not washed as well as normal in the previous process area. In this case the brightness would go lower compared to the kappa level and this would result in an increased ClO2 dosage as it should. The change in brightness could also be due to a change in bleachability of the pulp. If so, the correction to the ClO2 dosage would work in the same manner. The next measurement that influences the dosage is the chemical residual sensor. This sensor is located at some fixed time delay after the chemical mixer. The remaining chemical residual is compared to the ClO2 dosage calculation. Under normal conditions the residual sensor should trend very well with the dosage calculation and acts like a true dosage meter. Under upset conditions such as changes in carryover, bleachability, chemical strength, stock consistency, pH, or temperature the residual sensor will indicate either a higher or lower residual than normal compared to the dosage calculation. When this happens the controls will adjust the ClO2 dosage accordingly. The only other adjustment to the inlet control at this mill is that there is a production rate compensation that will adjust the dosage depending on how much the change in production rate affects the retention time of the stage which ultimately affects the efficiency of the stage. However, there are also two other influences to the overall ClO2 dosage. This comes from the feedback portion of the controls. The overall target of the D0 and Eop stages is to hit certain post Eop kappa and brightness targets. So there are two feedback controllers associated with this stage. The feedback controls employ a model predictive controller that is steadily correcting its model based on the resulting Eop kappa measurement from an online analyzer, and from an inline brightness sensor that is calibrated to be the actual
post Eop tower brightness. As the models begin to predict the kappa or brightness to be moving away from their setpoints, they will begin to adjust the ClO2 dosage to bring the MPC controller’s prediction back to the setpoints. What is important to notice here is that rather than trying to control the entire process with a MPC controller, these controls focus on stabilizing the process conditions that are critical to the stages performance and then adjusting the ClO2 dosage based on the incoming process conditions that cannot be controlled and determine how much ClO2 is needed. Once all of the inlet controls are in place, then two Model Predictive Feedback Controllers are used in parallel to adjust for any variance in the post stage kappa and brightness targets. The use of the online analyzer for measuring the Eop kappa is an established method for determining the post tower kappa. The use of the inline sensor for determining the Eop brightness has also been done before and if calibrated properly can work really well. However, the use of the brightness probe is more difficult to calibrate than an analyzer, since it is in the process line. This means the optical measurement sees all the variations of the process and the consistency of the stock can vary and cause inaccuracies if the probe is not correlated to compensate for consistency variations. Fortunately, the sensor used for this purpose has many different optical measurements and one of them correlates reasonably well to process consistency. This measurement can be used in a multivariable calculation along with the measurement that trends the best with the stock brightness to provide a post tower brightness that does not read incorrectly as the process consistency changes. An example of one of these calibrations is shown in Figure 1.

![Figure 1– Brightness Probe Calibration](image)

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This is an effective way to determine the post tower brightness of any bleaching stage. However, this method requires much more time to calibrate than does an online analyzer. An online analyzer pulls a sample from the process and then can wash the sample and control the consistency of the sample during its measurement. This eliminates any process variation other than the stock brightness from the measurement. The inline sensor will also require more follow up and lab checks for the same reason. Once the sensor is calibrated properly though, very effective controls schemes can be utilized using this measurement. Since this measurement is continuous instead of only at set time intervals like an analyzer, the control scheme is actually simpler to implement. Here is a screenshot of the display from the mill represented here shown in figure 2.

![Figure 2– D0 Operator Display](image)

This display is what the operators use to activate or deactivate the controls and also what they use to monitor the controls performance.
CONTROLLING THE Ep STAGE

Similar methods are used to control the amount of NaOH and H2O2 in the Ep stage. In this stage, the amount of NaOH is controlled to achieve a target terminal pH. The inlet NaOH dosage is based preferably on a reliable inlet pH measurement, but that was a real challenge at this mill due to issues with process scale. So, instead a ratio control strategy is applied that ratio’s the NaOH to the ClO2 dosage from the D0 stage. This ratio calculation is the only variable used for the feed forward NaOH control. However, the NaOH dosage is also corrected from a multi-predictive algorithm based on the pH after the stage. The terminal pH is controlled by adjusting the inlet NaOH dosage to achieve an Ep stage terminal pH setpoint. The terminal pH is measured and controlled from an inline pH sensor on the Eop washers filtrate.

Peroxide is also added to this stage to achieve a target brightness and kappa coming out of the Eop stage. This chemical is controlled based on the D0 stage retention time delayed kappa number. There are no inline residual or brightness probes on this stage, so these chemical dosages are set based totally on the delayed incoming kappa. However, the peroxide dosage is also then adjusted by a MPC feedback controller similar to the D0 stage and also using the same post Eop tower measurements that the D0 stages MPC controllers use. The same in-line brightness sensor is used to determine the brightness after this tower and the same on line analyzer is used to determine the kappa # that is used for the D0 stages feedback controls. The display for this stages control is shown in figure 3 on the next page. The operators use the display to monitor and control the Ep stage.

CONTROLLING THE D1 STAGE

The D1 stages pH is controlled using a method similar to the Eop stages pH control. At first, we tried to control this stages pH using an inlet pH probe that’s setpoint would be adjusted based on the D1 washers filtrate pH measurement and setpoint. However, due to unreliability of the inlet pH measurement, we switched the control scheme to use ratio control instead. We found that the amount of caustic needed on the D1 stage was really dependant on the amount of ClO2 that the stage used. So, by analyzing this data we developed a ratio curve based on the stages ClO2 dosage. The ClO2 dosage ratio determines the inlet pH control’s base amount of caustic that is applied to the stage. This amount is then adjusted according to a MPC controller’s prediction of the post towers filtrate pH versus the setpoint. As the prediction moves away from the setpoint the
controller will adjust the NaOH dosage to bring the prediction back to target. The prediction is always being updated against the press filtrates pH measurement.

The ClO2 dosage for this stage is controlled in a method really similar to the D0 stage with only slight differences. Instead of just a kappa factor based on the Eop kappa for the base level of ClO2, this stage also utilizes a brightness factor based on the Eop brightness. These two curves are used in parallel and weighted according to whether the inlet kappa or the inlet brightness predicts the stages outlet brightness the best. This stage also uses the inlet brightness sensor to convert the online kappa measurement to a continuous measurement as we do on the D0 stage. So, you have two main calculations that determine the amount of ClO2 to be applied to the stage based on the inlet kappa and the inlet brightness. You also have an adjustment based on the production rate and how much this affects the stages results. This feed forward portion of the controls is then adjusted based on the post towers MPC controller that is predicting the stages outlet brightness. This controller is using an inline brightness sensor similar to the Eop stages post tower brightness measurement to continuously correct its model. This probe is also

Figure 3– Ep Operator Display

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calibrated to be as independent of the process consistency as possible. This same sensor is then also used on the next stages (D2) feed forward controls. This MPC controller is always predicting the outlet brightness based on the inlet conditions. The MPC controller can only adjust the ClO2 dosage to bring its prediction back to setpoint as the inlet conditions change. So, the controller applies a ClO2 dosage adjustment to the feed-forward portion of the controls. The operator display that is used for this stage is shown on the next page in Figure 4. The operators use this display to monitor and control the D1 stage.

CONTROLLING THE D2 STAGE

The D2 stage is controlled similar to the D1 stage. This stage never had an inlet pH sensor, so we started with ratio controls for the caustic relative to the stages ClO2 dosage. This works really well to determine how much NaOH is needed to reach the post tower pH setpoint. However, we still use a post tower MPC controller that is comparing the stages filtrate pH prediction against its measurement and setpoint. Once again we have a
pH sensor on the washers filtrate. This sensor is used to continuously correct the MPC’s prediction. As the prediction moves away from the setpoint, the controller will adjust the caustic to bring the prediction back to the setpoint.

This stages ClO2 dosage feed forward controller is the simplest of the four stages. The reason for this is that by the time the stock has reached the D2 stage there is much less variation in the stock quality at this point, so not as many measurements are needed. Also, by this point there is no need to measure kappa anymore since most if not all of the lignin has been removed. So, the feed forward controls are only looking at a brightness factor based on the stages inline brightness sensor and the production rate. The feed forward based dosage is then adjusted according to the bleach plants final brightness sensor and MPC controller. This MPC controller is predicting the final brightness and adjusting the ClO2 dosage to keep the prediction at the setpoint. This controller is using an after tower brightness probe to continuously correct its model. Once again this brightness sensor is calibrated to be as consistency independent as possible. The operator display for this stage is shown in Figure 5 on the next page. The operators use this display to monitor and control the D2 stage.

![Figure 5– D2 Operator Display](image-url)
CONCLUSIONS

The measurements and controls used to optimize a modern bleach plant continue to be challenging and sometimes require different schemes than what is originally planned. It is very important to be able to recognize the relationships between each stages inlet conditions, chemical dosages, and the resulting after tower quality measurements. Once this is clearly understood, valid control schemes can be developed that take advantage of all the available measurements. If a needed inlet measurement is either problematic or not available, then the stages dynamics need to be studied so that the other available measurements and chemical relationships can be utilized instead. The mill and the vendor need to have the flexibility to adapt to overcome issues as they arise, because they certainly will. This project is a really good example of where there were several measurement issues that were ultimately overcome by utilizing alternate control schemes that did just that. Bleaching chemicals are the second highest cost next to wood cost per ton of pulp, so there is huge potential for significant savings when good measurements and control schemes are utilized correctly. Chemical cost are extremely high in South America so this project produced great savings at this mill. The optimization summary page that shows the ClO2 savings and other process variables is shown in figure 6.

![Figure 6 – ClO2 Optimization Summary Display](Distributed with permission of author by ISA 2014)

The NaOH optimization summary page is shown in figure 7.

![Image of NaOH Optimization Summary Display]

**Figure 7 – NaOH Optimization Summary Display**

The reason the controls work so well at this site is that the controls use the reliable measurements from an on-line kappa and inline brightness sensors, residual sensors, and pH sensors when available. When there were issues with any of the measurements that could not be overcome, then alternate but effective control schemes were utilized instead. The controls are compensated relative to changes in the production rate, bleachability, consistency, carryover, temperature, and pH by utilizing the in-line sensors. The pulp is tracked through each stage via multi-predictive controllers that use uncertainty factors to compensate for variations in retention time and measurement delays. Also, the controls are designed so that each stages chemical dosage can be compensated relative to the production rate. This helps to compensate for changes in bleach plant efficiency relative to variable retention times.

Also, from thoroughly analyzing the controls it can be concluded that the post-stage measurements are critical to modeling and controlling the process accurately. This
project also proves that inline brightness sensors can be used as an alternative to online analyzers to deliver significant savings. These sensors can provide very accurate lab quality results, but they will still need to be cross checked against the lab on a periodic schedule. The post-stage measurements are used in a similar strategy on each bleaching chemical and in each bleaching stage. The individual stage controls are combined to provide an overall bleach plant optimization strategy. When these controls are used properly they provide benefits in chemical savings, controlling the final brightness to a desired level, and improved quality by reducing the final pulp property variation.

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