Predictive Adaptive Control Aids Pulp Digestion

New software provides closed-loop control at Skeena Cellulose; $0.60/ton cost reduction cooks up into $100,000 savings per year for each digester.

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Digestion is a hot topic in pulp production at Skeena Cellulose in Prince Rupert, British Columbia, Canada. A new continuous digester control system uses a new predictive adaptive process controller to provide closed-loop control of Effective Alkali and reduced Kappa Number variability. The installation of this controller has resulted in production cost savings of $0.60 per ton of pulp and projected savings of more than $100,000 annually for each of two digesters. Production deviations have been reduced, yielding more uniform and salable pulp.

To achieve these results, Skeena is using Brain Wave, a new predictive adaptive process controller capable of controlling processes with long dead time and automatically adapting to process changes. Previous predictive controller designs (such as Smith Predictor and other model-based controller designs) at the Skeena mill had been inadequate because of an inability to adapt to variations in process dead time as well as the setup and maintenance required.

Too much dead time for PID

Controlling Effective Alkali is difficult due to the long dead time between changes in white liquor flow and measured residual Effective Alkali. This dead time can reach 3.5 hours and is not suited to control with conventional proportional-integral-derivative (PID) controllers. A model-based predictive controller is required to close loops with such long dead times.

The relationship between Effective Alkali and pulp Kappa Number is shown in two reaction mechanisms in the digester. Initially, alkali concentration decreases rapidly due to a variety of physical and chemical mechanisms that depend on wood chip quality. After these...
initial reactions, bulk delignification begins. The reaction rate during this phase strongly depends on alkali concentration. The concentration at the start of this phase is called the residual Effective Alkali.

Effective Alkali (EA) is defined as the sum of the sodium hydroxide concentration plus one half of the sodium sulphide concentration expressed as grams of Na₂O per liter. EA is difficult to measure because the liquor must be analyzed after initial reactions have occurred. In a single-vessel Kamyr digester, initial reactions are complete in the lower cooking zone. Therefore an on-line Effective Alkali analyzer can provide measurements approximately every 30 min.

Wide variances; control model

However, even with the measurement problem solved, Effective Alkali control remains a problem. While EA is sensitive to variations in chip quality, this property is difficult to measure and employ in a feedforward control strategy. Skeena’s chip moisture varies from 40% to 60% during a day’s production. Without the ability to implement open-loop feedforward control, the only option for Effective Alkali regulation is feedback control to improve digester operation. The mill installed a Kappa Number control system in 1989. This system is based on a fixed model relating Kappa Number, H factor, sulphidity, and Effective Alkali. The model coefficients are determined using laboratory Kappa Number tests. The target Kappa is 32 and the installation of this control system has reduced standard deviation from 3.76 to 3.38 despite wide swings in chip quality. Residual EA set point is 0.7 lb/ft³ with a historical standard deviation of 0.08 EA. In 24 hours, the measured EA ranges from more than 0.8 to less than 0.6, crossing the target of 0.7 eight times.

Cascading benefits

Reducing the standard deviation of EA will help make it easier to determine accurate coefficients for the Kappa Number prediction model. Kappa Number predictions will improve as the model is refined for a smaller range of operating conditions (after EA variations are reduced). With improved Effective Alkali control, changes in target H factor would also be smaller, resulting in reduced temperature and steam demand swings. Stable digester operation would contribute to reduced pulp property variations and smoother operation of the bleach process, also on site.

BrainWave field installations operate up to 32 process loops from a single computer running Microsoft Windows NT. BrainWave software is said to reduce process variability 30-50%.

The new control strategy was implemented using a model-based, predictive adaptive process controller called BrainWave, from Universal Dynamics Technologies (Vancouver, British Columbia, Canada). The controller runs in a personal computer and communicates with the distributed control system via a serial link. The diagram shows the configuration.
BrainWave monitors the EA measurement from the on-line analyzer and calculates the setpoint for the white liquor/wood ratio controller. The ratio controller is used to compensate for short-term variations in wood chip mass flow while BrainWave adjusts the ratio target based on longer term changes in chip properties. The black liquor flow rate is incorporated into BrainWave as a feedforward input to compensate for changes in Effective Alkali caused by black liquor used to clear chip hang-ups in the digester.

BrainWave was installed and setup to observe digester operation for several weeks. During this time, the controller automatically constructed process transfer function models for the relationship between Effective Alkali and the white liquor/wood ratio target as well as the relationship between effective alkali and black liquor flow.

Following this observation period, the controller was placed in automatic and adjusted the white liquor/wood ratio target to maintain constant EA. While in automatic control, the BrainWave continued to adapt the transfer function models as required to compensate for changes in process operating conditions in order to maintain optimal control.

**Three-month trial**

A three-month trial checked various Kappa targets and standard deviations using the new BrainWave control system saved $0.60 per metric ton of pulp, dropping production costs of Scandinavian Pine Kraft Pulp to about $399 per metric ton. (Cost at zero deviation would be about $396 per ton.) Once multiplied by the total annual output of one Kamyr digester for this mill, savings totalled $108,885 per year. Return on investment was less than five months.

It should be noted that the calculations used are conservative as the Kappa number standard deviation (SD) used are the average of daily averages for all cases, which will tend to understate the SD and the potential savings.

With improved Effective Alkali control, changes in target H factor are small. With smaller changes in H factor, temperature...
setpoint variations are smaller. Reduced variations in temperature setpoint dampen steam demand swings, which reduce energy costs and smooth digester and boiler operation. With reduced swings in Effective Alkali, pulp properties such as viscosity are more consistent.

New optimization techniques can be used to investigate the economics of several process units affected by digester operation. Lower variation in Kappa number will smooth out bleach plant operation and reduce the load on the effluent treatment system. By reducing the alkali added to the digester, the load on the chemical recovery system is reduced.

Because adaptive, predictive control with feedforward capabilities and automatic process model building at Skeena controls Effective Alkali, Kappa number deviations have been reduced, resulting in a more uniform and salable product. Optimization techniques can now be used to find the most economical operating point for the digester, bleach plant, effluent treatment system and chemical recovery system.

The ability of BrainWave’s Dynamic Modeling Technology to learn the process and feedforward variable behavior automatically and continuously enables the simple and cost-effective implementation of advanced controls. DMT techniques can be used to ensure optimum control system performance with a reduction in the maintenance effort required to support advanced controls. The problems of long development time, long setup time, repeated tuning and poor reliability associated with other advanced controllers are solved with the DMT method.

The application of BrainWave at Skeena Cellulose has recently been expanded to include the second digester and effluent pH control. Effluent control application gain varies from 1.5 to 0.25. The time constant varies from 1 to approximately 5 min. And the dead time is generally about 15 min. Future application to the bleach plant is planned.

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