Advanced Fuel/Air Control for B&W Kraft Black Liquor Recovery Boilers

**FIGURE 1** Typical Kraft Recovery Cycle

**Introduction**

The recovery boiler provides critical functions in pulp and paper mills. It operates on (1) recovery of pulp in chemical sludge (2) disposal of waste from the pulp process, (3) production of steam for electric power generation and process use. These functions are critical to the economic success of Kraft pulp plants. By reducing the costs of chemistry makeup, process waste disposal, electrical power, and fuel, steam generation becomes more efficient. Because of the high efficiency and interaction of the operation of Kraft pulping and recovery operations, minor variations in parts of the process can be propagated and amplified throughout the mill. Consequently, favorable economics can be quickly changed to unfavorable economics by ineffective process control.

To stabilize chemical recovery and steam generation on Kraft black liquor recovery boilers, it is necessary to compensate for normal variations in black liquor composition, and normal variations in combustion temperature, pressure and humidity. Conventional recovery boiler control strategies do not effectively prevent these variations. However, the advanced control strategy presented in this application guide for Babcock & Wilcox (B&W) recovery boilers takes advantage of the unique features of the Bailey NETWORK 90 computer-based distributed control system to automate control variables for these variations, with improved boiler operation and improved safety.
Summary of Advanced Control Benefits

Application of the Baley NETWORK 90 recovery boiler advanced fue/air control with ammonia being fed to the furnace. The benefits include:

- **Stabilized recovery boiler operation**
- **Improved combustion efficiency**
- **Reduced and stabilized coal reduct on efficiency**
- **Increased and stabilized oxygen concentration**
- **Less auxiliary fuel for bed stability at reduced back pressure**
- **More mized sulfur losses in stack emissions**
- **Contributed towards more mized sulfur and/or salt cake makeup for the Kraft recovery cycle**
- **More mized operator intervention during process upsets**
- **Erha-ced recovery boiler operation on a safety basis**

Process Description

A typ ca Kraft chem ca recovery cycle s shown schematically in FIGURE 1. Th s diagram illustrates the re at onsh p and importance of the recovery boiler n the chemical and heat balance of a typical pulp mill.

Wood ch ps are converted to p ip n ether contuous or batch digesters us ng caustic white liquor and steam to 'cook' the ch ps. The white liquor reacts with th and d sso ves the various organ ca n fs from the wood ch ps produc ng weak back liquor. The weak back liquor s washed from the caustic pulp concentrated to form heavy back liquor and sent to the recovery boiler as fuel. In the furnace of the recovery boiler, the gas ns from the back liquor are burned to generate steam and the spent pulp p chemical ca s are reduced to form a molten state. The steam is dissolved in weak wash water from the caustic zone area to form green liquor. The green liquor then reacts with produced white liquor for the pulp cook rig, thus completing the chemical recovery cycle.

The white liquor used to cook wood ch ps is a water solution of sodium hydroxide (NaOH) and sodium sulfide (Na2S). After digestion the wood ch ps the liquor consists of sodium carbonate (Na2CO3), sodium sulf ate (Na2SO4), and various organ ca inns removed from the wood. In the recovery boiler, the organ ca mater als are burned, form ng ah gh temperature reduc ng atmosphere where sodium sulf ate (Na2SO4) is converted to sodium sulf ide (Na2S). Sodium carbonate passes through the recovery furnace unchanged but is later converted to sodium hydroxide (NaOH) when the green liquor is recaustized with the addition of hydrated lime (Ca(OH))2.

At the recovery boiler heavy back liquor (63-66% so ds) s heated for vscons ty control and sprayed into the recovery furnace. The quors that are sprayed on the se wa s of the furnace where water and the more vo at e hydrocarbons vapor ze the rema nng char fakes off the wa and f a s to the floor of the furnace. The vo at e hydrocarbons and some of the quors are burn ng the hot combust on ga suspens on, bu t most of the so ds burn n a layer of char on top of the sme t bed at the floor of the recovery furnace.

The air used for combus on of the back quors is preheated and fed into the recovery furnace through three separate y controlled zones. Primary air enters the furnace near the sme t bed to sup port combus on of the quor so ds. Primary a ir 45-55% of the a r requ red for tota combus on of the quor sol ds. Th s creates a chemical reduc ng atmosphere for convert ng sodium sulf ate to sodium sulf ide. Secondary Air s used to trim the top of the char bed and prov de more pre cise con tro of hydro ys s (drying of the back quor so ds). Tertiary air s added tangent ally on the upper reg on of the furnace to burn the vo at e hydrocarbons and to prov de the turbu ent gas f ow requred n the steam generator bank for eff c dent heat transfer.
Effect ve chm ca recovery and eff c cnt steam product on depend on proper control of these air flows. If too much secondary and/or tertiary air is used for a spec fc b ack quor f r ng rate, the excess air acts as a heat sink and carries heat out the recovery boiler stack rather than produces steam. If too much primary air is used for the back liquor firing rate, the sulfide reduct on reaction in the smelt bed will be inhibited and recovery of the pu p ng chm ca s w not be max zed.

The required airflows are a function of the smoke content of the back quor, as well as the back quor firing rate. For example, quor have a 63% smoke content will require more air for combustion than liquor with a 66% solids content. The heat value of the weaker quor is lower (more water). Further, the composition of the back quor solids varies with the specifics of wood used and the strength of the wet quor used to dry the wood. These compositions on the variation of the secondary and/or tertiary air are masked by changes in the secondary and/or tertiary air flow. The combustion of sodium sulfide to sodium sulfate also increases the bed temperature and causes excessive smelt run off.

These reactions produce measurable increase in the fluegas CO concentration and sulfur stack emissions, as well as a decrease in sodium sulfide to sodium sulfate. These reactions produce an increase in fluegas CO concentration. However, for stable secondary air flow, tertiary air flow, and back quor composition, an increase in the fluegas CO concentration can be interpreted as an increase in too much oxygen near the char bed.

**Conventional Control Strategy**

The conventional control strategy for B&W recovery boilers is shown in FIGURE 2 and is primarily based on the control of the secondary and/or tertiary air flow. Some models have added control for the rate of primary air and/or secondary air flow to the back quor feedrate. The conventional control strategy can provide stable steam generation and chemical recovery only if the back quor solids content/composition ratio and combustion air rate temperature/pressure/flow rate remain stable for extended periods of time. Because of the high-temperature interactions, the nature of the various elements in the furnace recovery process, this stability is an extremely rare circumstance.

\[
\text{Na}_2\text{S}_2\text{O}_3 + 2\text{C} \rightarrow \text{Na}_2\text{S} + 2\text{CO}_2
\]

The reaction requires the high-temperature reducing atmosphere generated by incomplete combustion on the black liquor solids.
Advanced Control Strategy

The advanced recovery boiler fuel/air control strategy presented in this paper is shown schematically in Figure 3. The strategy relies on NETWORK-90 control modules, as well as cost-effective communicating processors. The features of the advanced control strategy are:

- Automatic control of LIQUOR SOLIDS feedrate to the recovery boiler. The liquor volume is automatically controlled to compensate for variations in the solids content of the back liquor.

- Automatic control of TOTAL A/R/LIQUOR SOLIDS and PRIMARY AIR/L QUOR SOLIDS ratios. The TOTAL A/R and PRIMARY A/R feedrates to the recovery boiler are automatically adjusted to compensate for variations in the LIQUOR SOLIDS feedrate.

- Automatic control of SECONDARY A/R/PR MARY A R ratio.

- Automatic control of the combustor outlet pressure. This monitors the flow rate of the TERTIARY A/R.

- Automatic adjustment of the TOTAL AIR/QUOR SOLIDS ratio to control the excess oxygen concentration in the recovery furnace. This is done by providing a coarse adjustment for fuel use and carbon monoxide concentration.

- Automatic adjustment of the PRIMARY AIR/QUOR SOLIDS ratio to stabilize the carbon monoxide concentration in the recovery furnace.

- Automatic computation of the recovery boiler performance index (LB STEAM/LB QUOR SOLIDS). This parameter is used for logging and trend analysis.

- Automatic compensation for auxiliary fuel usage.

- Automatic boiler backout prediction.

- Fault tolerance of the advanced control function for loss of any process measurement signal.

These features are provided by "cascade" controllers which send remote setpoints to the base regulatory controllers (flow, temperature, and/or pressure). With the base controllers in the CASCADE mode, the operator can change the recovery boiler load by simply changing the fuel flow setpoint. The various a/f ow s w automat ca y change to m n m ze excess oxygen and stablize the carbon monoxide concentration in the fuel gasses.

Black Liquor Control

Refer to Figure 3, the advanced recovery boiler fuel/air control strategy provides a stable massrate of back liquor solids to the recovery boiler through F C 4B. This is part of a higher priority to maintain a constant heat release for stable boiler steam generation and a constant chemical recovery rate for stable green liquor product on (quant ty and quality).

The black liquor volume is controlled (FT 4) automatically, adjusted to compensate for variations in the back liquor solids concentration. The advanced strategy utilizes an on-line concentration sensor (DT-4), such as the process refractometer generator. Sufficient signals are provided for closed loop control, the advanced controller automatically switches itself to MANUAL mode.

Total Air Control

The advanced recovery boiler fuel/air control strategy provides a stable heat release (per pound of back liquor solids) for stable steam production. The rate of total combustion air (mass basis) to back liquor solids (dry basis), TOTAL A/R/QUOR SOLIDS, is controlled by RIC 1 to a precise compensation (feedforward) for variations in the back liquor solids content. RIC 1 provides the remote setpoint to F C 1, which adjusts the tertiary air damper.
The total A/R/L QUOR SOLIDS ratio s automat ca y adjusted (w th n m ts) by A C 1 A to ma nta n a spec fed target for f uegas oxygen concentration, this compensates for variat ons n the sto ch ometr c combust on a r requ ments of the b ack quor and m n m zes the heat o ss from excess ve n trogen n the f uegas. To ensure ade quate turbe ence for eff cient heat transfer to the steam generat ng bank, the excess oxygen target s programmed as a funct on of f r ng rate to a ow h gher oxygen concentrat ons at ower f r ng rates thereby prov d ng more combust on a r and cor respond ng y h gher f uegas f ow s at reduced f r ng. Further, f the f uegas CO concentrat on s too high (above 400 PPM) the total AIR/ LIQUOR SOLIDS ratio s automatica y increased s ght y by AC 1 B unt the CO concentrat on s w th n range for contro by A C 3 through adjust ment of the PRIMARY AIR/ LIQUOR SOLIDS ratio s.

The total A/R volume flow (FT 1) s compen sated for temperature (TT-1) dur ng ca cu at on of the total A/R mass rate by F C 1 f this temperatur e s gna s unava lab e for use n the ca cu at on R C 1 uses a prev ous y val d va ue until the signal can be restored. f the black quor so ds target becomes unava ab e for use n the rat o ca cu at on contro automat ca y and b ump ess y reverses from rat o contro by R C 1 to TOTAL AIR volumetr c flow control by FIC-1 f the f uegas oxygen concentrat on s gna (AT-7A) becomes unava lab e to the advanced contro system the oxygen contro er (A C 7 A) s automat ca y and b ump ess y sw tched to MANI AL mode w th the setpo nt for FIC 1 held at ts ast va d va ue f the f uegas CO concentrat ion signal (AT 7 B) becomes unava bed, the bias ng act on from AC 1 B s frozen unti the s gna s restored.

Primary Air Control

The advanced recovery bo er fue l a r contro strategy prov des a stab e reduc ng environ ment for chem ca recovery The rat o of pr mary com bust on a r (mass bas s) to b ack quor so ds (dry bases) is control by RIC 3 to quickly compen sate (feedforward) for variat ons n the b ack quor so ds content Th s rat o s automat ca y adjusted (w th n m ts) by A C 3 to ma nta n a set concentration of CO in the recovery furnace f uegas.

Secondary Air Control

The secondary a r flow is contro ed by R C 2 to ma nta n a constant SECONDARY AIR/ PR MARY A R rat o Th s rat o setpo nt s typ ca y 50% f the PRIMARY A R volumetr c f ow rate s gna l (FT 3) becomes unava ab e for use n the rat o ca cu at on contro automat ca y and b ump ess y reverses from ratio contro by R C 2 to SECONDARY AIR vo umetr c flow contro by F C 2.

Draft Control

The net vanes to the forced draft combust on a r fan are modu ated to ma nta n a constant duct pressure n the combust on a r header for the recovery furnace. The setpo nt for PIC 1 is se ected to prov de the requ red pr mary, secon dary and tertiary airflows.

Compensation for Auxiliary Firing

The advanced contro ers cont nuous y mon tor the aux ar y f r ng fue l (FT-5) and prov de a feedfor ward adjustment of both the total AIR/ L QUOR SOL DS rar o and the PR MARY A/R/ L QUOR SOL DS rar o to compensate for changes Th s adjust ment is based on the sto ch ometr c combustion air requirements for the auxiliary fuel. The f uegas oxygen and carbon monox de tr m contro ers prov de any add ona adjustment necessary n these rat os to stab ze chem ca recovery and minimize heat losses.
Bed Blackout Prediction

The advanced back quor controller (F C 4B) continuously calculates a quor combustion performance index (LCP, pounds of steam per pound of back quor solids). The calculation determines boiler steam flow from FT 6 and PT-6, and divides it by the quor solids firing rate. Any steam generated by auxiliary firing (FT 5) is subtracted from the total steam flow before the LCP calculation. The LCP can be logged to document the performance of the recovery boiler as a steam generator and quantify improvements over previous recovery boiler control strategies.

The LCP can also be trended as a continuous indicator of recovery boiler performance. An abrupt decrease in the LCP can be used as an early warning of impending bedackout. The advanced controller monitors the LCP for an abrupt, significant decrease in the LCP and automatically takes control action to reduce the potentia l of an actual bedackout. The control action generally utilized for avoiding bedackout is to increase the temperature setpoint for the back quor line heater temperature controller (TIC 4) and to prevent the oxygen controller (A C 1A) from reducing the TOTAL A R/L QUOR SOL DS rate.

Fault Tolerances

There is extensive interaction between the various advanced control loops for the recovery boiler. Several process measurement signals may be input into one advanced control loop. Conversely, one signal may be input to several of the advanced control loops. The loss of any one of these signals may have a widespread effect on the advanced control system or a very limited effect. Further, the loss of one specific signal may have a major impact on one control loop and a minor impact on others.

To minimize the effect of an unavailable process measurement signal on the performance of the advanced control system, and on the operation of the recovery boiler, specific interlock features have been designed into the advanced recovery boiler control system. These interlocks prevent inappropriate action by the various control loops and maintain the highest level of control system functionality possible under abnormal conditions.
Basic Control Strategy for a B&W Recovery Boiler

Advanced Control Strategy for a B&W Recovery Boiler
The advanced controller receives information from a variety of sensors, and the output of any one sensor causes the advanced controller to automatically act on the control systems. The system is designed to respond quickly to changes in the environment. When the base control loops are engaged in the NETWORK 90, the primary measurement signal for the base controller becomes unavailable to the base controller and the automatic control cycle is switched to the Manual mode.

In all cases, the operator is alerted to the automatic controller act on. When the signal becomes available to the control system again, the affected control functions can be restated by the operator.

**Economic Analysis**

On a typical 800 Ton/Day back-quar recovery boiler, a total annual savings of $143,000 can be realized by reducing the average excess air from 28% to 10% (excess oxygen reduced from 4.5% to 2%) using programmed oxygen trim control. The net steam production increases from the reduced excess air reduction on the steam network that need not be produced by the boiler. The addition of axygen to the steam reduces the oxygen in the boiler and fuel costs. The savings are based on 350 operating days/year and a cost for generating steam of $3.50/MBtu. Actual savings will vary from month to month depending on the power boiler fuel costs and other factors affecting recovery boiler ability to fire at reduced excess air. The calculation of these savings is shown in FIGURE 4.

Additions to economic gains can be realized in other areas of the recovery boiler, such as improved chemical reduction, reduced SO2 and TRS emissions, reduced dust carryover to the boiler tube banks, and overall lower fly ash for stability at reduced back-quar firing rates. Further increased green quars will reduce the load on the causticizing department and reduce soda ash mud and brown stock washers.

**Implementation**

The Bayley Controls NETWORK 90 distributes an emergency processor-based control system offering cost-effective and flexibleumpedment on the advanced Kraft recovery boiler fuel/air control strategy. The advanced strategy can be therapeutically engaged in the NETWORK 90 recovery boiler or controller modul. The NETWORK 90, along with an emergency power controller module (NMFC01), offers a reliable and cost-effective solution to providing separate total primary air, secondary air, and O2 quars, quars temperature, and auxiliary fuel control. These modules can be therapeutically integrated into a complete NI TWORK 90 recovery boiler control system, or installed as a stand-alone NETWORK 90 system to provide on-the-fly advanced fundamental units out of service.

Operator interface can be provided by any of the Bayley CRT-based operator consoles or panels mounted DGTA Control Statons (NDCS03 10 each). Typical hardware, such as spays, is shown in FIGURE 5 and FIGURE 6. The manual operating spays (FIGURE 5) gives the operator an overview of recovery boiler operation and provides access to the control loops w-thout changing the spays. The detailed spays (FIGURE 6) provides the operator with specific functional feedback on process control capabilities for start-up, and respond to abnor mal/suspect ons.

The capabilities and features of the referenced NETWORK 90 equipment are further described in the Bayley Product Spec cations. The NETWORK 90 module configuration is required to be engaged for Kraft recovery boilerers may be purchased from Bayley Controls subject to a software license and use agreement. For systems configured by Bayley, all system sketchnes and documentation are available for download on the Bayley control software's.
**BENEFIT:** Reduced power boiler auxiliary fuel consumption due to a reduction in excess combustion air.

- 800 [TON pu p] / DAY
- 350 DAY / YEAR
- 3000 [LB back quor so ds] / [TON pu p]
- 3.2 [LB steam generated] / [LB back quor solids]
- (28.10) [% excess a r in fluegas]
- 0.084 [% fue savings @ 370°F fluegas temperature] / [% excess a r in fluegas] / 100%
- $3.00 [fue cost] / [m on BTU]
- 850 [LB steam] / [m] on BTU

$143,000 savings / YEAR

*Figure 4  Economic Benefit Calculations*
FIGURE 5  Typical Overview Graphic Display for a Recovery Boiler
FIGURE 6  Typical Detail Graphic Display for a Recovery Boiler