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Application Guide

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

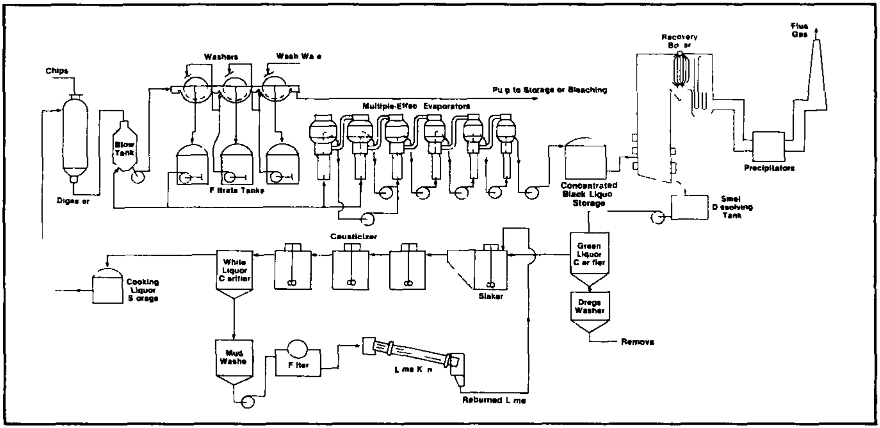

FIGURE 1 Typical Kraft Recovery Cycle

Introduction

The recovery boiler provides three critical functions in pulp and paper mill operation: (1) recovery of pulping chemicals, (2) disposal of waste from the pulping process, (3) production of steam for electrical power generation and process use. These functions are critical to the economics of the Kraft pulping process through reductions in the costs of chemical make up, process waste disposal, electrical power and fuel for steam generation. Because of the highly integrated and interacting nature 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 by Kraft black liquor recovery boilers, it is necessary to compensate for normal variations in black liquor solids content and composition, and normal variations in combustion air temperature, pressure and humidity. Conventional recovery boiler control strategies do not effectively provide this compensation. However, the advanced control strategy presented in this application guide for Babcock and Wilcox (B&W) recovery boilers takes advantages of the unique features of the Bailey NETWORK 90 microprocessor based distributed control system to automatically compensate for these variations, simplify operation of the recovery boiler, and improve its operational safety.

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Babcock & Wilcox, a McDermott company

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Summary of Advanced Control Benefits

Application of the Bailey NETWORK 90 recovery boiler advanced fuel/air control will result in the following benefits:

- Stabilized recovery boiler operation
- Improved combustion efficiency maximizing steam production per pound of black liquor solids fired. This will minimize the high cost of operating power boilers to satisfy process demands, and can result in an annual savings of as much as $70/TPD of rated capacity for each percentage reduction in fluegas oxygen concentration.
- Increased and stabilized reduction efficiency. This will result in stabilizing the relative concentration of sodium sulfide in the green liquor.
- Less auxiliary oil firing for bed stability at reduced black liquor firing.
- Minimized sulfur loss in stack emissions. This will contribute towards minimizing the sulfur and/or salt cake make up for the Kraft recovery cycle.
- Minimized operator intervention during process upsets.
- Enhanced recovery boiler operational safety.

Process Description

A typical Kraft chemical recovery cycle is shown schematically in **FIGURE 1**. This diagram illustrates the relationship and importance of the *recovery boiler in the chemical and heat balances* of a typical pulp mill.

Wood chips are converted to pulp in either continuous or batch digesters using caustic white liquor and steam to 'cook' the chips. The white liquor reacts with and dissolves the various organic lignins from the wood chips producing weak black liquor. The weak black liquor is washed from the cellulose pulp, concentrated to form heavy black liquor, and sent to the recovery boiler as fuel. In the furnace of the recovery boiler, the lignins from the black liquor are burned to generate steam and the spent pulping chemicals are reduced to form a molten salt smelt. The smelt is dissolved in weak wash water from the recausticizing area to form green liquor. The green liquor is then recausticized producing white liquor for the pulp cooking, *thus completing the* chemical recovery cycle.

The white liquor used to cook wood chips is a water solution of sodium hydroxide (NaOH) and sodium sulfide (Na_2S). After digesting the wood chips, the liquor consists of sodium carbonate (Na_2CO3), sodium sulfate (Na_2SO_4) and various organic lignins removed from the wood. In the *recovery boiler, the organic materials are burned,* forming a high temperature reducing atmosphere where sodium sulfate (Na_2SO_4) is converted to sodium sulfide (Na_2S). Sodium carbonate passes through the recovery furnace unchanged, but is later converted to sodium hydroxide (NaOH) when the green liquor is recausticized with the addition of hydrated lime ($Ca(OH)_2$).

At the recovery boiler, heavy black liquor (63-66% solids) is heated for viscosity control and sprayed into the recovery furnace. The liquor is sprayed on to the side walls of the furnace, where water and the more volatile hydrocarbons vaporize, the remaining char flakes off the wall and falls to the floor of the the furnace. The volatile hydrocarbons and some of the liquor solids burn in the hot combustion gas suspension, but most of the solids burn in a layer of char on top of the smelt bed at the floor of the recovery furnace.

The air used for combustion of the black liquor is preheated and fed into the recovery furnace through three separately controlled zones. **Primary air** enters the furnace near the smelt bed to support combustion of the liquor solids. Primary air is 45-55% of the air required for total combustion of the liquor solids; this creates a chemically reducing atmosphere for converting sodium sulfate to sodium sulfide. **Secondary Air** is used to trim the top of the char bed and provide more precise control of hydrolysis (drying of the black liquor solids). **Tertiary air** is added tangentially in the upper regions of the furnace to burn the volatile hydrocarbons and to provide the turbulent gas flow required in the steam generator bank for efficient heat transfer.

Effective chemical recovery and efficient steam production depend on proper control of these air flows. If too much secondary and/or tertiary air is used for a specific black liquor firing 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 black liquor firing rate, the sulfide reduction reaction in the smelt bed will be inhibited and recovery of the pulping chemicals will not be maximized.

The required airflows are a function of the solids content of the black liquor, as well as the black liquor firing rate. For example, liquor having a 63% solids content will require less air for combustion than liquor with a 66% solids content since the fuel heating value of the weaker liquor is lower (more water). Further, the composition of the black liquor solids varies with the species of wood digested and the strength of the white liquor used to digest the wood. These composition variations have a significant effect on the stoichiometric air requirements for each pound of black liquor solids (dry basis) fired, and are the major disturbances which must be compensated for to stabilize operation of the recovery boiler.

With respect to steam production, measurement of the excess oxygen concentration in the recovery furnace fluegas provides an indication of how effectively the secondary and/or tertiary airflow is being controlled. Higher levels of excess oxygen in the fluegas indicate that too much secondary and/or tertiary air is being added and the corresponding nitrogen is carrying heat out with the fluegas rather than generating steam.

With respect to chemical recovery, measurement of the carbon monoxide (CO) concentration in the recovery furnace fluegas provides an indication of how effectively the primary air is being controlled. The primary chemical recovery reaction in the recovery furnace is the conversion of sodium sulfate to sodium sulfide in the char bed.

$$Na_2SO_4 + 2C \longrightarrow Na_2S + 2CO_2$$

This reaction requires the high-temperature reducing atmosphere generated by incomplete combustion of the black liquor solids.

If too much primary air is added, undesirable reactions consume both the carbon critical to the recovery reaction and the required products of the recovery reaction.

$$2C + O_2 \longrightarrow 2CO$$

$$Na_2S + 2O_2 \longrightarrow Na_2SO_4$$

$$Na_2S + 4CO_2 \longrightarrow Na_2CO_3 + 3CO + SO_2$$

These reactions produce a measurable increase in the fluegas CO concentration and sulfur stack emissions, as well as a decrease in smelt sulfidity. The combustion of sodium sulfide to sodium sulfate also increases the bed temperature and causes excessive smelt run off.

The increased fluegas CO concentration caused by excessive primary airflow can be easily masked by changes in the secondary and/or tertiary combustion airflow(s). Conversely, a decrease in secondary or tertiary air can produce an increase in fluegas CO concentration. However, for stable secondary airflow, tertiary airflow and black liquor composition/feedrate, an increase in the fluegas CO concentration can be interpreted as an indication of too much oxygen near the char bed.

Conventional Control Strategy

The conventional control strategy for B&W recovery boiler control is shown in **FIGURE 2** and is principally a base regulatory control system (single element pressure, temperature and flow controllers). Some mills have added control for the ratio of primary and/or secondary airflow(s) to black liquor feedrate. The conventional control strategy can provide stable steam generation and chemical recovery only if the black liquor solids content/composition/rate and combustion air temperature/pressure/humidity remain stable for extended periods of time. Because of the highly interactive nature of the various elements in the pulping/recovery process, this stability is an extremely rare circumstance.

Advanced Control Strategy

The advanced recovery boiler fuel/air control strategy presented in this application guide is shown schematically in **FIGURE 3.** This strategy relies on NETWORK 90 controller module intercommunication and computational capabilities to provide control features previously available only with expensive centralized process computers. *The specific features of the advanced control* strategy are:

- Automatic control of LIQUOR SOLIDS feedrate to the recovery boiler. The liquor volumetric flowrate is automatically modulated to compensate for variations in the solids content of the black liquor.
- Automatic control of TOTAL AIR/LIQUOR SOLIDS and PRIMARY AIR/LIQUOR SOLIDS ratios. The TOTAL AIR and PRIMARY AIR feedrates to the recovery boiler are automatically varied to compensate for variations in LIQUOR SOLIDS feedrate.
- Automatic control of SECONDARY AIR/PRIMARY AIR ratio.
- Automatic control of the combustion air duct pressure. This indirectly controls the flow of TERTIARY AIR.
- Automatic adjustment of the TOTAL AIR/LIQUOR SOLIDS ratio to minimize the excess oxygen concentration in the recovery furnace fluegas and to provide a coarse adjustment for *fluegas carbon monoxide concentration.*
- Automatic adjustment of the PRIMARY AIR/LIQUOR SOLIDS ratio to stabilize the carbon monoxide concentration in the recovery furnace fluegas.
- Automatic computation of the recovery boiler combustion performance index (LB STEAM/LB LIQUOR SOLIDS). This parameter is available for logging and trending.
- Automatic compensation for auxiliary fuel firing.
- Automatic bed blackout prediction.
- Fault tolerance of the advanced control functions 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 all the base controllers in the CASCADE mode, the operator can change *recovery boiler load by simply changing the* LIQUOR SOLIDS setpoint, or change auxiliary firing simply by changing the fuel flow setpoint. The various airflows will automatically change to minimize excess oxygen and stabilize the carbon monoxide concentration in the fluegas.

Black Liquor Control

Referring to **FIGURE 3**, the advanced recovery boiler *fuel/air control strategy provides a stable* massrate of black LIQUOR SOLIDS to the recovery boiler through FIC-4B. This is particularly important to maintaining a constant heat release for stable recovery boiler steam generation and a constant chemical recovery rate for stable green liquor production (quantity and quality).

The black liquor volumetric feedrate (FT-4) is automatically adjusted to compensate for variations in black liquor solids concentration. The advanced strategy utilizes an on-line concentration sensor (DT-4), such as the process refractometer generally provided for recording black liquor solids concentration. In the event that DT-4 suddenly becomes unavailable for closed loop control, the advanced controller automatically and bumplessly reverts to volumetric feedrate control by FIC-4A. If the primary flow signal (FT-4) is lost, FIC-4A 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 black liquor solids) for stable steam production.* The ratio of total combustion air (mass basis) to black liquor solids (dry basis), TOTAL AIR/LIQUOR SOLIDS, is controlled by RIC-1 to quickly compensate (feedforward) for variations in the black liquor solids content. RIC-1 provides the remote setpoint to FIC-1, which adjusts the tertiary air damper

The TOTAL AIR/LIQUOR SOLIDS ratio is automatically adjusted (within limits) by AIC-1A to maintain a specified target for fluegas oxygen concentration; this compensates for variations in the stoichiometric combustion air requirements of the black liquor and minimizes the heat loss from excess velnitrogen in the fluegas. To ensure adequate turbulence for efficient heat transfer to the steam generating bank, the excess oxygen target is programmed as a function of firing rate to allow higher oxygen concentrations at lower firing rates, thereby providing more combustion air and correspondingly higher fluegas flows at reduced firing. Further, if the fluegas CO concentration is too high (above 400 PPM), the TOTAL AIR/LIQUOR SOLIDS ratio is automatically increased slightly by AIC-1B until the CO concentration is within range for control by AIC-3 through adjustment of the PRIMARY AIR/LIQUOR SOLIDS ratio.

The total air volumetric flow (FT-1) is compensated for temperature (TT-1) during calculation of the total air massrate by FIC-1. If this temperature signal suddenly becomes unavailable for use in the calculation, RIC-1 uses a previously valid value until the signal can be restored. If the black liquor solids target becomes unavailable for use in the ratio calculation, control automatically and bumplessly reverts from ratio control by RIC-1 to TOTAL AIR volumetric flow control by FIC-1. If the fluegas oxygen concentration signal (AT-7A) becomes unavailable to the advanced control system, the oxygen controller (AIC-7A) is automatically and bumplessly switched to MANUAL mode with the setpoint for FIC-1 held at its last valid value. If the fluegas CO concentration signal (AT-7B) becomes unavailable, the biasing action from AIC-1B is frozen until the signal is restored.

Primary Air Control

The advanced recovery boiler fuel/air control strategy provides a stable reducing environment for chemical recovery. The ratio of primary combustion air (mass basis) to black liquor solids (dry basis) is controlled by RIC-3 to quickly compensate (feedforward) for variations in the black liquor solids content. This ratio is automatically adjusted (within limits) by AIC-3 to maintain a set concentration of CO in the recovery furnace fluegas.

The measured primary air volumetric flow (FT-3) is compensated for temperature (TT-1) during calculation of the primary air massrate by RIC-3. If this temperature signal suddenly becomes unavailable for use in the calculation, RIC-3 uses a previously valid value until the signal can be restored. If the black liquor solids target becomes unavailable for use in the ratio calculation, control automatically and bumplessly reverts from ratio control by RIC-3 to primary air volumetric flow control by FIC-3. If the fluegas CO concentration signal (AT-7B) becomes unavailable, the CO controller (AIC-3) is automatically and bumplessly switched to MANUAL mode with the setpoint for RIC-3 held at its last valid value.

Secondary Air Control

The secondary air flow is controlled by RIC-2 to maintain a constant SECONDARY AIR/PRIMARY AIR ratio. This ratio setpoint is typically 50%. If the PRIMARY AIR volumetric flowrate signal (FT-3) becomes unavailable for use in the ratio calculation, control automatically and bumplessly reverts from ratio control by RIC-2 to SECONDARY AIR volumetric flow control by FIC-2.

Draft Control

The inlet vanes to the forced draft combustion air fan are modulated to maintain a constant duct pressure in the combustion air header for the recovery furnace. The setpoint for PIC-1 is selected to provide the required primary, secondary and tertiary airflows.

Compensation for Auxiliary Firing

The advanced controllers continuously monitor the auxiliary firing fuel flow (FT-5) and provide a feedforward adjustment of both the TOTAL AIR/LIQUOR SOLIDS ratio and the PRIMARY AIR/LIQUOR SOLIDS ratio to compensate for changes. This adjustment is based on the stoichiometric combustion air requirements for the auxiliary fuel. The fluegas oxygen and carbon monoxide trim controllers provide any additional adjustment necessary in these ratios to stabilize chemical recovery and minimize heat losses.

Bed Blackout Prediction

The advanced black liquor controller (FIC 4B) continuously calculates a liquor combustion performance index (LCPI, pounds of steam per pound of black liquor solids). The calculation determines boiler steam flow from FT 6 and PT-6, and divides it by the liquor solids firing rate. Any steam generated by auxiliary firing (FT 5) is subtracted from the total steam flow before the LCPI is calculated. The LCPI 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 LCPI can also be trended as a continuous indicator of recovery boiler performance. An abrupt decrease in the LCPI can be used as an early warning of impending bed blackout. The advanced controller monitors the LCPI for an abrupt, significant decrease in the LCPI and automatically takes control action to reduce the potential of an actual bed blackout. The control action generally utilized for avoiding bed blackout is to increase the temperature setpoint for the black liquor line heater temperature controller (TIC 4) and to prevent the oxygen controller (AIC 1A) from reducing the TOTAL AIR/LIQUOR SOLIDS ratio.

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, special interlocking 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.

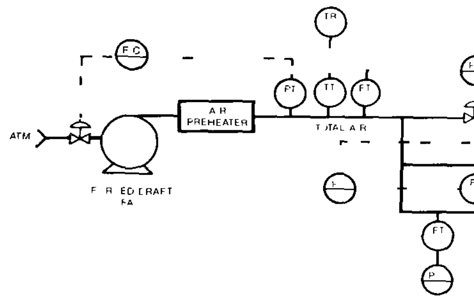


FIGURE 2 Conve

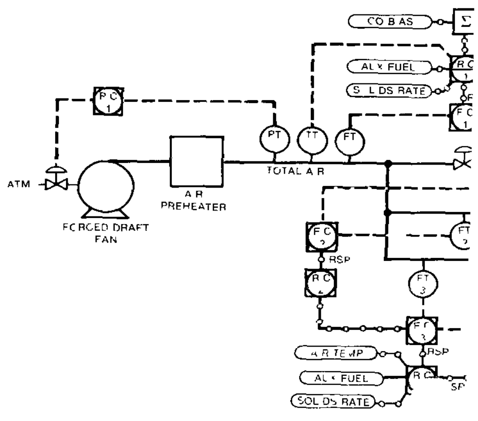
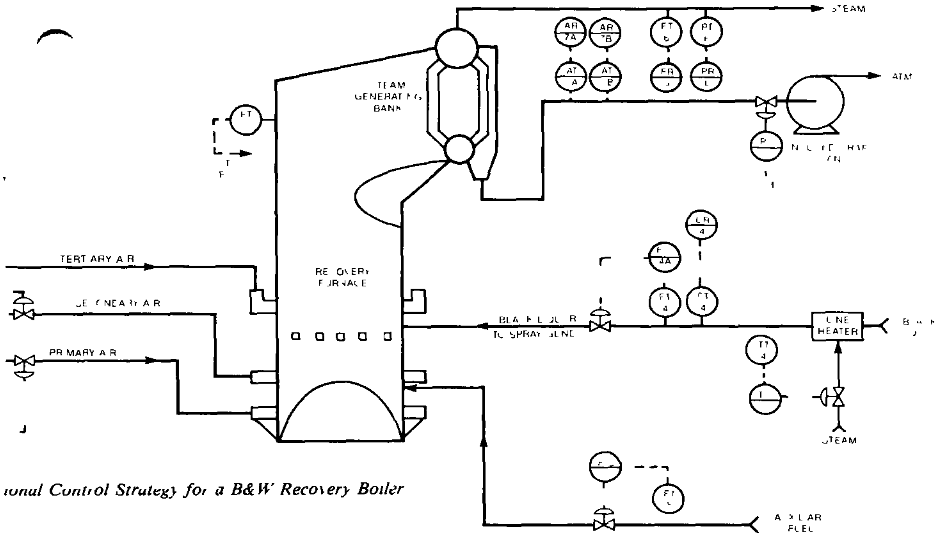


FIGURE 3



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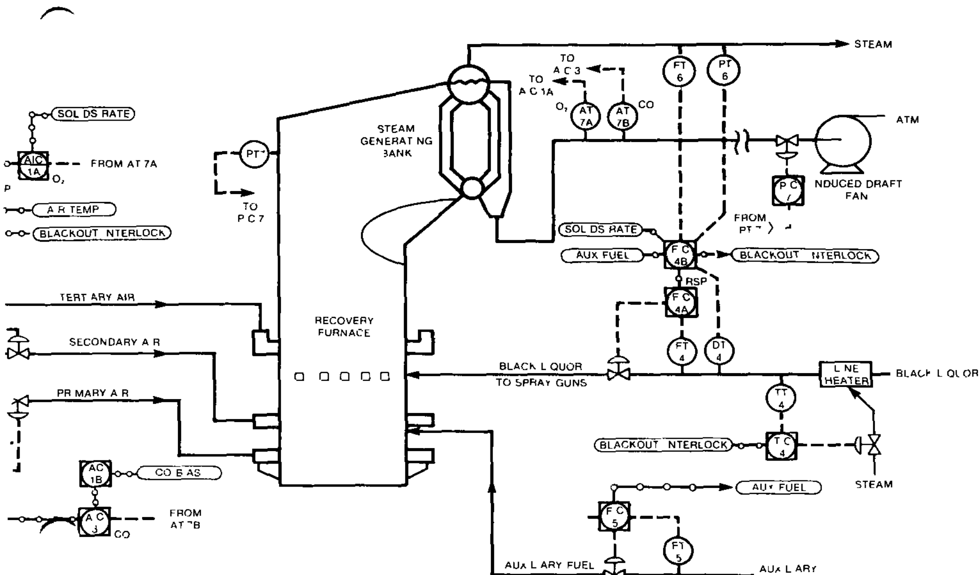

anced Control Strategy for a B&W Recovery Boiler

The advanced controller receives information from a variety of sensors, and the loss of any one signal causes the advanced controller to automatically initiate an interlock action. If the lost signal is not dynamically critical to the advanced loop, the controller will use a previously valid value of the signal. If the lost signal is dynamically critical to the advanced control function, the advanced controller will hold the remote setpoint for the base controller at a previously valid value.

When the base control loops are implemented in NETWORK 90, if the primary measurement signal for the base controller becomes unavailable, the base controller is automatically and bumplessly *switched to* MANUAL *mode*.

In all cases, the operator is alerted to the automatic interlock action. When the signal becomes available to the control system again, the affected control functions can be bumplessly reinstated by the operator.

Economic Analysis

On a typical 800 Ton / Day black liquor recovery boiler, a total annual savings of $143,000 can be realized by reducing the average excess air from 28% to 10% (excess oxygen reduction from 4.5% to 2%) using programmed oxygen trim control. The net steam production increase from this excess air reduction represents steam that need not be produced by power boilers fired with fossil fuel. This savings is based on 350 operating days / year and a cost for oil generated steam of $3.50 / MLB. Actual savings will vary from mill to mill depending on the power boiler fuel cost and other factors affecting recovery boiler ability to fire *at reduced excess air*. The calculation of these savings is shown in **FIGURE 4**.

Additional 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 less auxiliary oil firing for stability at reduced black liquor firing rates. Further, increased green liquor sulfide concentration will reduce the load on the causticizing department and reduce soda loss in the lime mud and brown stock washers.

Implementation

The Bailey Controls NETWORK 90 distributed microprocessor based control system offers cost effective and flexible implementation of the advanced Kraft recovery boiler fuel/air control strategy. The advanced strategy can either be implemented in eight (8) independent but intercommunicating single loop control modules (NCOM03, or equivalent) or in a single multi-loop control module (NMFC01). For optimum reliability and fault tolerance, the eight single loop controllers should be partitioned to provide separate total air, primary air, secondary air, draft, CO and O2, liquor, liquor temperature and auxiliary fuel controllers. These modules can either be integrated into a complete NETWORK 90 recovery boiler control system, or installed in a stand alone Micro 90™ system to provide only the advanced functions outlined.

Operator interface can be provided by any of the Bailey CRT based operator consoles or panel mounted Digital Control Stations (NDCS03 10 each). Typical dynamic graphic displays for OIU operation of the recovery boiler are shown in **FIGURE 5** and **FIGURE 6**. The main operating display (**FIGURE 5**) gives the operator an overview of recovery boiler operation and provides access to the critical control loops without changing displays. The detail display (**FIGURE 6**) provides the operator with specific information and control capabilities for start up and responding to abnormal situations.

The capabilities and features of the referenced NETWORK 90 equipment are fully described in the various Bailey Product Specifications. The NETWORK 90 module configurations required to implement this advanced fuel/air control strategy for Kraft recovery boilers may be purchased from Bailey Controls subject to a software license and use agreement. For systems configured by Bailey, the system diskettes and documentation will include the configurations. For systems not configured by Bailey, *a detailed implementation guide* is available.

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 b ack quor so ds] / [TON pu p]

* 3 2 [LB steam generated] / [LB b ack quor solids]

* (28 10) [% excess a r n fluegas]

* 0 084 [% fue sav ngs @ 370°F f uegas temperature] / [% excess a r in f uegas]

/ 100%

* $3 00 [fue cost] / [m on BTU]

/ 850 [LB steam] / [m l on BTU]

$143,000 sav ngs / YEAR

FIGURE 4 Economic Benefit Calculations

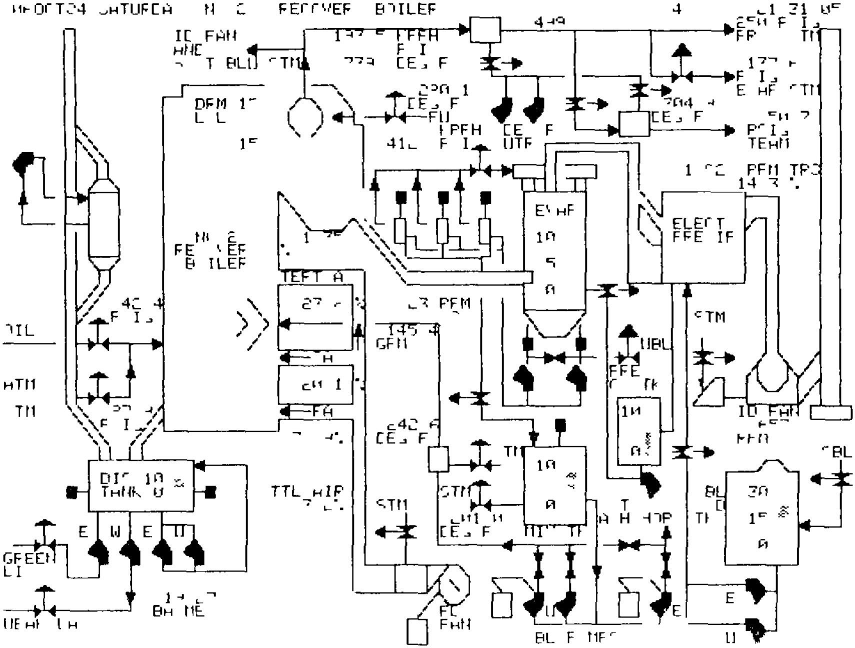

FIGURE 5 Typical Overview Graphic Display for a Recovery Boiler

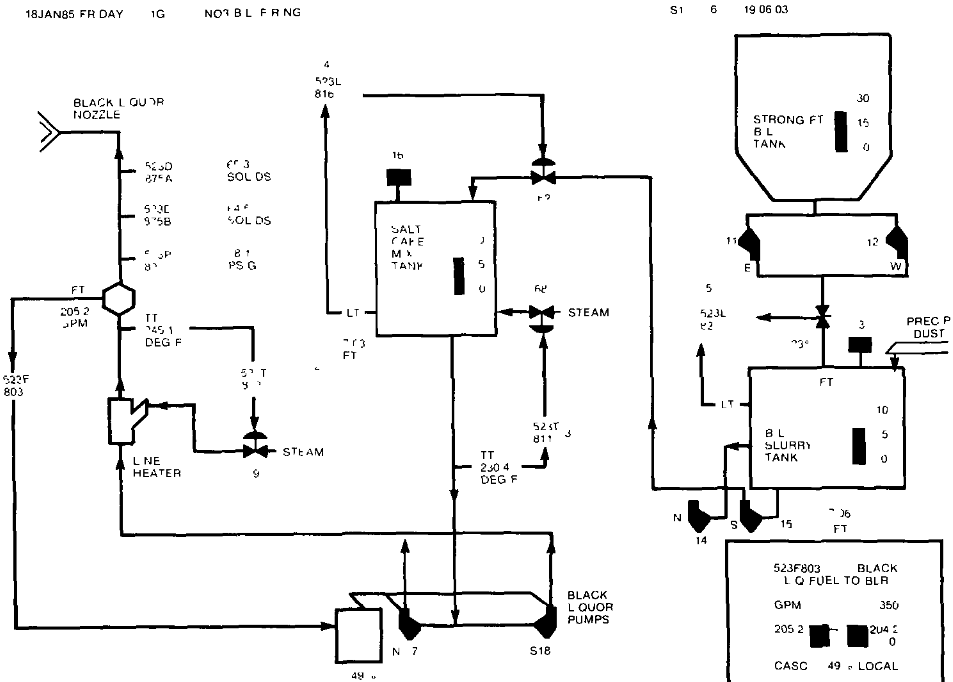

FIGURE 6 Typical Detail Graphic Display for a Recovery Boiler

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