Upgrading a recovery unit for low-odor operation and greater capacity

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The capacity of a 20-year-old recovery unit was expanded to accommodate a scheduled increase in pulp production. The new emission requirements were met by replacing the cyclone evaporator with steam-driven concentrators.

The 600-ton[1] recovery boiler at the James River mill in St. Francisville, La., was built and started up in 1966. In 1985, the mill began planning to upgrade this boiler. Plans to upgrade the boiler were based on three factors:

- Results obtained from a tube-thickness measurement program indicated that pressure parts in the lower and middle furnace, upper arch, and generating bank were nearing the end of their useful lives. Projections indicated that these parts would have to be replaced in 1988 if the boiler was to continue normal operation.
- The mill was considering an increase in pulp production that would require a 24% increase in boiler capacity.
- The boiler was having difficulty in maintaining its TRS (total reduced sulfur) emissions within the compliance requirement of 20 ppm. It appeared that the direct-contact cyclone evaporator and wet-bottom precipitator would have to be modified if the boiler was to comply with the 20-ppm limit. The proposed 24% increase in capacity would require an emission limit of 5 ppm.

Together, these three issues provided the company with compelling reasons to replace or rebuild the recovery boiler.

Rebuild options

Two options were considered in response to the recovery boiler situation: (a) build a new boiler on a nearby greenfield site or (b) rebuild the existing unit and convert it to low-odor operation. A new boiler was quickly eliminated because of cost. A much larger boiler was not considered because further expansion of pulp production would require millwide equipment changes, and there were no plans to do this in the foreseeable future. In addition, running a new recovery boiler at half load was deemed unwise.

The rebuild option seemed to be the logical choice. A low-odor conversion at another of the company's mills (Wauna, Ore.) had just been completed, so we were familiar with the requirements of such a project. In addition, the early planning ensured that there would be sufficient time and financial resources to rebuild the boiler using good design practices.

The initial phases of the project began in the summer of 1986. Approval was received in February 1987. This was to be a fast-track project in order to prevent premature shutdowns due to pressure-part thinning. The boiler pressure parts were ordered in March 1987.

Project objectives and design options

The B&W boiler in the St. Francisville mill, originally designed in 1964, is illustrated in **Fig. 1**. It is a short ("squat") recovery steam generator rated at 1.8 million pounds (600 tons) of black-liquor solids per day. The boiler is fitted with a direct-contact cyclone evaporator for concentrating black liquor. Design steam production was 275,000 lb/h of 750°F superheated steam firing 6600-Btu/lb black liquor (66% solids) at 220°F using a splash-plate oscillator and three-level air-combustion system.

The major objectives of the rebuild project were to:

- Reduce gaseous emissions
- Increase solids-firing capacity by 50% above the original design while attaining a minimum continuous run time of six months between water washes.

[1]In the context of this paper, 1 ton is equal to the heat input from 3000 lb of solids with a heating value of 6600 Btu/lb · h for 24 h.

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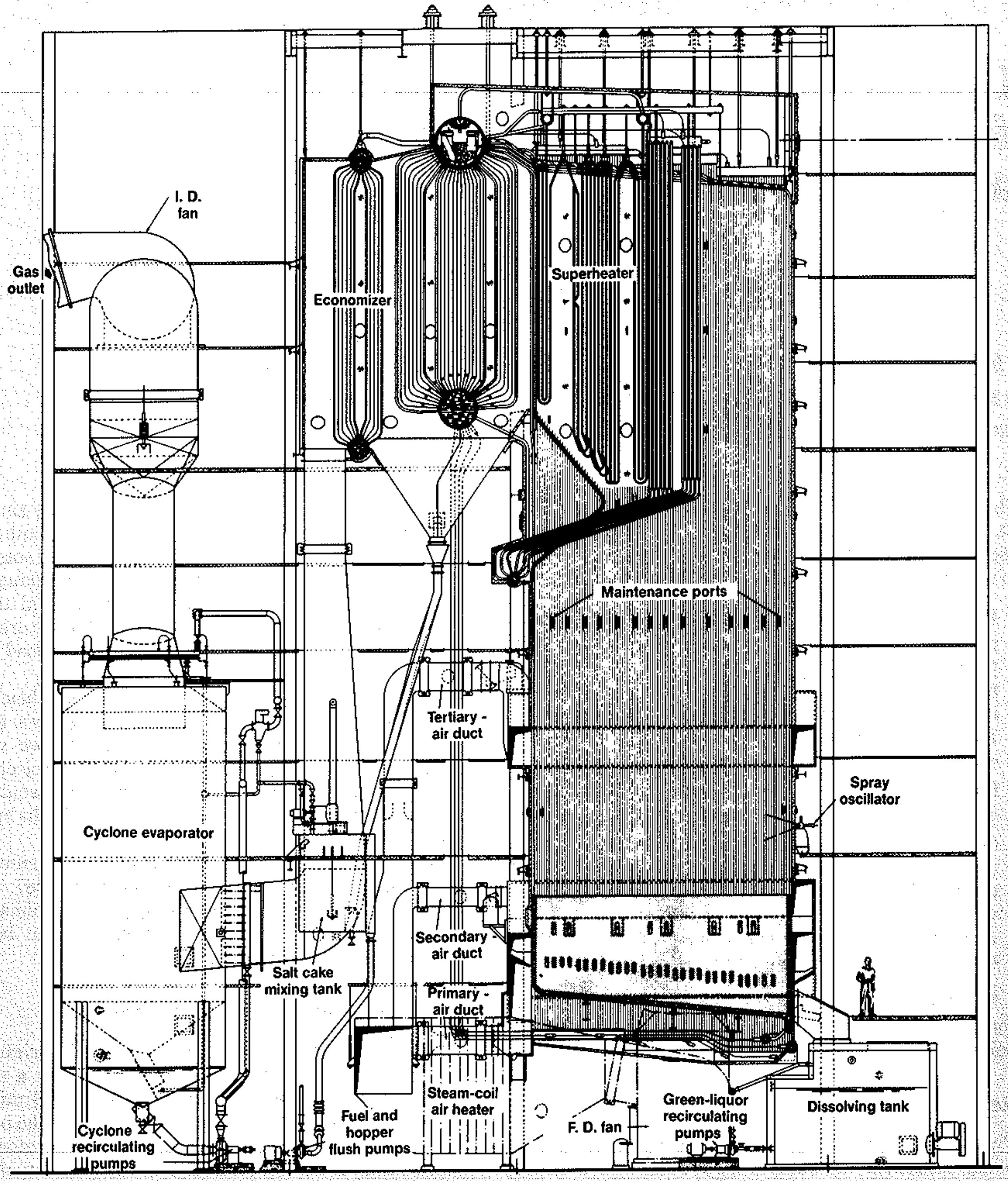
1. Original boiler design



A variety of design options were evaluated. These options, as well as the final design approach, are examined in the context of the project's major objectives.

Reduction of gaseous emissions

Several recovery boilers have been converted for low-odor operations, and the associated costs and environmental benefits are well documented.[2]

The direct-contact evaporator in a recovery boiler is a prime source of malodorous emissions. When a boiler is converted to a low-odor configuration, the cyclone-type direct-contact evaporator is eliminated and replaced with steam-driven concentrators, which are added to an existing evaporator set. This arrangement provides a higher solids concentration than that obtained using direct-contact evaporators. This approach also improves energy utilization and thus reduces the cost of energy.

Multiple-effect, indirect evaporation is an efficient way to remove moisture from the black liquor because it uses low-pressure exhaust steam. The heat energy that was formerly used to evaporate moisture in the direct-contact evaporator is instead used to produce additional low-cost, high-pressure steam. This conversion strategy thus provides economic benefits as well as environmental benefits.

Our plans were to add a long-flow economizer to capture the flue-gas heat that was being used in the evaporator. The economizer increases the thermal efficiency of the steam generator (typically from 50% efficiency to 56%), which improves the furnace's liquor-to-steam generation ratio. The long-flow economizer consists of eight modules, each a 50-ft-long, two-header design. The economizer is finned, with each tube having two 2.5-in. fins, one in the front and one in the rear, spaced 180° apart. The outside diameter of the tubes is 2 in., with a 0.180-in. wall. This heat trap increases the system's thermal efficiency and results in greater steam generation for the same heat input.

Beneath the new long-flow economizer, two trough-type hoppers, rotary seals, and two drag conveyors were added to complete the ash system. The accessories added to the economizer system included sootblowers, hinged access doors, and special observation doors (to check for trough bridging). With higher-solids black liquor (typically about 70%), there is a consequent decrease in the evaporation load within the recovery furnace and a reduction in flue-gas weights. This further reduces the liquor-to-steam generation ratio and improves the thermal efficiency of the system from 56% to about 64%.

These changes would allow the mill to operate within the specified low-emission guideline. In addition, experience with similar projects indicated that the higher operating efficiency would allow the capital expenditure for these improvements to be recaptured within 2–4.5 years, depending on the fuel-displacement assumptions utilized.

Increased solids-firing capacity

The second project objective involved increasing the solids capacity to 150% of the original design's maximum continuous rating (MCR) while achieving a continuous run time of six months.

Each process-recovery steam generator has a series of process limitations that can become "choke" points. These limitations must be identified and modified if potential bottlenecks are to be eliminated. We applied this philosophy to our project.

It was apparent that the low-odor conversion would generate more steam. Thus it was necessary to determine how the boiler circulation and the resulting increase in steam capacity would affect the superheater pressure drop. If any capacity limitations were encountered, we could plan appropriate modifications to eliminate them.

Before the rebuild, the boiler was experiencing high TRS emissions as well as convection-pass plugging. This indicated that a combustion-related choke point had been reached at the solids-processing levels that were being used. The low-odor conversion provided the opportunity to review the combustion system and upgrade it to current state-of-the-art levels to meet the objectives of increased run time, optimized performance, and reduced combustion-related emissions. Reconfiguring the short, squat recovery unit to successfully process a 50% increase in design solids represented the major challenge and was the cost-effective alternative to purchasing a new unit.

Furnace size

It was clear that the existing furnace volume (residence time) and hearth area were insufficient to adequately process the quantity of solids that would be required when pulp production was increased. The actual performance of the recovery unit, which was operating at 123% of the original design's MCR, was measured and compared with the original design predictions and with current design standards. These data provided a benchmark from which performance predictions were extrapolated to the 150% objective over the original design's MCR.

To gain the confidence necessary to guarantee a six-month continuous run at the upgraded conditions, two typical operating extremes within the database were utilized to set outer limits, which helped to quantify the operational risks involved. For example, Unit A, operating at 145% of the original design's MCR for a continuous 350 days/year, was compared with Unit B, operating at 135% of the original design's MCR for a continuous 42 days between water washing. Once these boundaries were established, they were modified to take into account variations in liquor inert chemistry, steam-generator operating pressure, final steam temperatures (thermal load), and physical variations such as superheater side spacing (bridging potential). A summary of the empirical factors reviewed are provided in **Table I.**

This analysis reconfirmed that upgrading the mill's recovery unit would involve increasing furnace volume (for longer residence time) as well as furnace plan area (for an increase in hearth–air interface area and reduction in furnace-gas velocities).

Increased furnace volume. Two approaches were considered to obtain additional furnace volume: (a) lower

[2]Coulture, H. D. Jr. and Schweizer, W. P., "Low odor conversion of the Temple Eastex No. 3 recovery unit—a case study," 1982 Pulping Conference Proceedings, TAPPI PRESS, Atlanta.

the floor or (b) raise the roof. In either case, walls would need to be moved outward to obtain a reasonable hearth area for the new liquor load.

- Lowering the floor would provide a maximum height gain of 8 ft. It also would require rotating the dissolving tank 90° and constructing a pit for the tank and its accessories. Other factors involved in lowering the floor were: auxiliary equipment clearances, installation of a sump system, and modifications to the existing structural footings. Lowering the floor also would require relocation of the operating platform, primary-air platform, fuel piping, electricals, and controls.
- Raising the roof would require the addition of one elevation, boiler and building column extensions, new perimeter steel, a building penthouse, vertical relocation of the drums and existing economizer, extension of stairs, replacement of salt-cake sluice lines, relocation of sootblower piping, and relocation and extension of main steam piping.

After analysis, it was determined that raising the roof was the most cost- and time-effective approach. It also posed the lowest safety risk. How high to raise the roof? The database provided the boundaries, and computer iterations balancing furnace exit-gas temperatures against fouling potential and superheat/screen surface requirements indicated that a 9-ft addition was the most effective solution.

Increased furnace depth. The shaft velocity and the surface area of the interface between the bed and the primary air could not remain constant with the higher throughput. Initial plans were to move each side wall and the front wall out 2 ft, but this approach was discarded because of its high cost. The front wall could be relocated outboard without disturbing the boiler's main support columns. Once again, the database provided the boundaries, and computer iterations balanced the furnace exit-gas temperature (at the new height) against plug-flow shaft velocities, surface requirement for hearth interface, and the destruction/redesign of platforms and associated light support steel. Results indicated that pushing the front wall out a distance of 7 ft was the best solution. The depth increase turned an essentially square furnace (26.5 ft × 22.5 ft) into a rectangular furnace (33.5 ft × 22.5 ft). This shape would affect the design of the combustion system, and it was decided to model the air-flow/mixing carefully to optimize the size and location of the air ports.

Combustion system

The low-odor configuration provides black-liquor fuel at a higher solids content. Fuels that have been better prepared can be fired in alternative ways to take advantage of the preparation energy expended. However, the air system of the recovery unit had to be upgraded to accommodate (a) the change in firing conditions permitted by the higher solids and (b) the new rectangular cross section within the furnace.

Air flow. The combustion-air system, i.e., the distribution, penetration, and mixing of combustion air, has been demonstrated to be a cost-effective upgrade.[3] The three-air-zone application effectively matches the special combustion requirements inherent with firing black liquor: dehydration, devolatilization, and a combination of suspension and pile burning. However, data taken from this unit indicated that the original tertiary air system was not capable of being fully utilized because of a lack of sufficient fan static pressure. Furnace probes showed the presence of internal gas-recirculation patterns, indicating that the interior of the furnace was not being fully utilized for gas flow. This resulted in increased furnace gas peak velocities (above 1200 ft/min) which, in turn, increased entrainment of solid particles. Additionally, the flow of flue gas from the bed formed a column in the center of the furnace, and the tertiary air could not effectively penetrate this column. The data indicated that the mill was not attaining good furnace mixing and the system could be improved. The change to rectangular cross section also would require a new mixing configuration. Objectives were set for improving the mixing: effectively utilize furnace volume, reduce solid-particulate entrainment, contain the fireball, and reduce TRS emissions from the boiler.

System model. A one-sixth scale model of the proposed upgraded unit was constructed and isothermally tested for various air-port configurations. The new primary ports were held constant while varying both the size and location of tertiary and secondary ports.

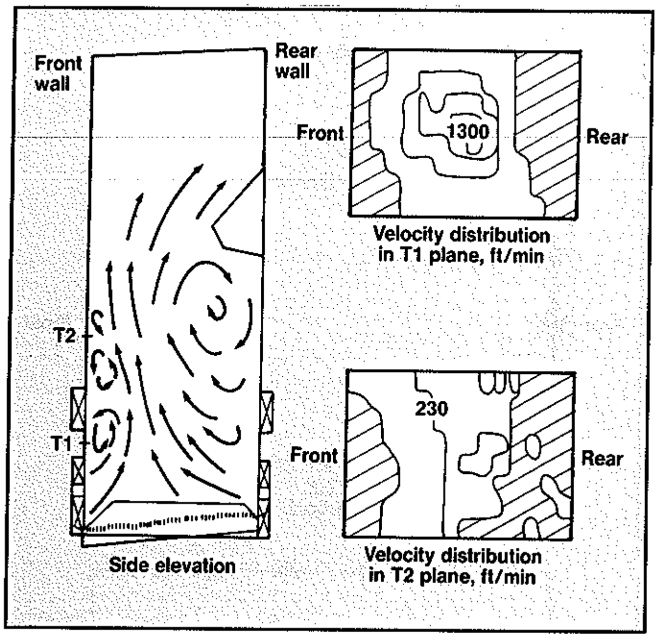
Utilizing the results from other ongoing modeling efforts, we went directly to our preferred arrangements as a starting point for the upgrade (150% of MCR) model baseline. Primary air ports were arranged on all four walls (our standard practice). Secondaries were modeled on all four walls and separately on side walls only. Tertiaries were modeled on side walls and separately on front/rear walls. The model was used to evaluate results obtained by varying static pressures, degree of offset, and 90° shear-plane effects. **Figure 2** illustrates the baseline configuration resulting from the flue-gas pattern. The velocity patterns from two planes—above and below the tertiary ports—are also illustrated.

Many variations and iterations were run, resulting in a recommended configuration. The recommended flue-gas patterns are shown in **Fig. 3.** The configuration of secondary and tertiary air ports that achieved the mixing objectives are described in the following paragraphs.

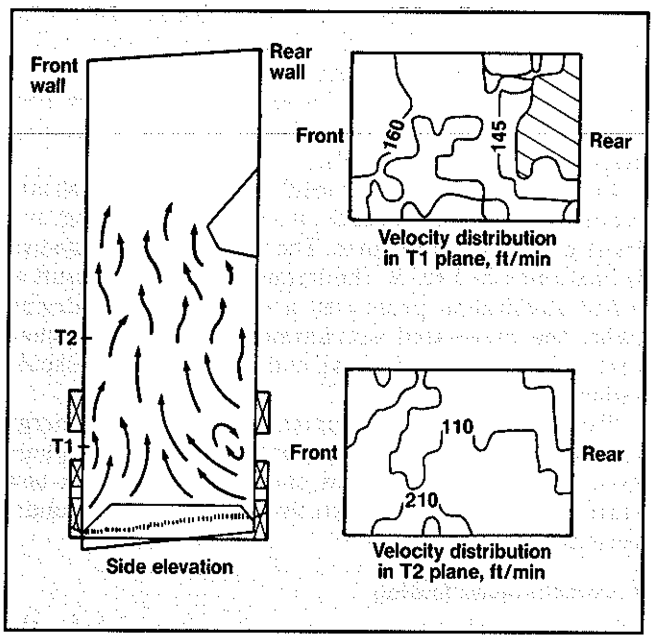
Tertiary air system. Tertiary air provides oxygen to complete the combustion of the volatile gases and aids in total furnace mixing to reduce both peak velocities and peak gas temperatures. The optimal configuration utilized nozzles that were offset horizontally front to rear. No nozzle directly opposed any other nozzle, a pattern that is characterized as "interlaced." Static pressure at the nozzles was modeled over a range from 8 in. (wg) to 20 in. (wg), with flows from 10% to 25% of total air. The best combination (i.e., eliminated recirculation of furnace gas and penetrated the column) was found to be 12 in. (wg) static pressure and 12% of total air. A tertiary port damper was designed with variable port control and has been applied to finalize the tertiary air system. The port damper is illustrated in **Fig. 4.** A total of seven ports were applied, with four on the front wall and three on the rear wall (long penetration), each sized 4 in. × 23 in. The tertiary system uses cold air.

[3]Barsin, J. A., 1989 Kraft Operations Seminar, TAPPI PRESS, Atlanta, p. 223.

2. Baseline air-flow isotherms



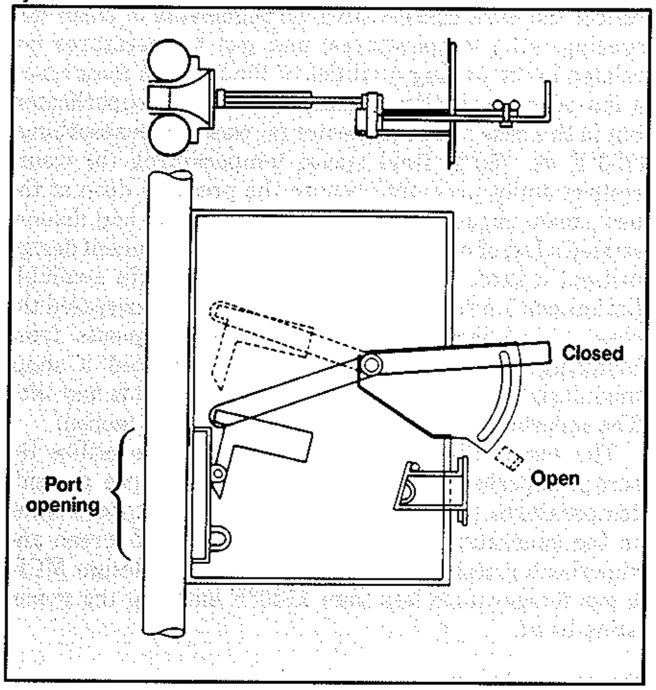
3. Final air-flow isotherms



I. Boundary conditions (Units A and B) used to determine parameters for rebuilt unit

	Unit A (145% MCR; 350 days)	*Unit B (135% MCR; 42 days)*	*St. Francisville unit*	
			Before rebuild	*After rebuild*
Plan area, Btu/ft²	19.30	24.34	27.71	21.95
Furnace volume, ft³/ton	38.8	47.8	37	47.2
Plan area, lb solids/ft²	3191	4195	4600	3643

4. Guillotine-type variable-velocity port damper for use in tertiary air system



Secondary air system. Secondary air provides oxygen for combustion of the volatile gases and aids in the dehydration and pyrolysis of the liquor. Effective distribution and penetration are critical for bed control and combustion. The upgrade and the fuel-preparation improvements together would put more liquor directly on the bed. The proposed secondary system was baseline modeled, and improvements in coverage/penetration were identified. A total of 13 secondary ports (4 in. × 27 in.)—10 "interlaced" on the side walls, two others on the rear wall, and one on the front wall—were determined to be the best arrangement. Air-flow measuring devices and controls provide the operational flexibility required to match different operational conditions.

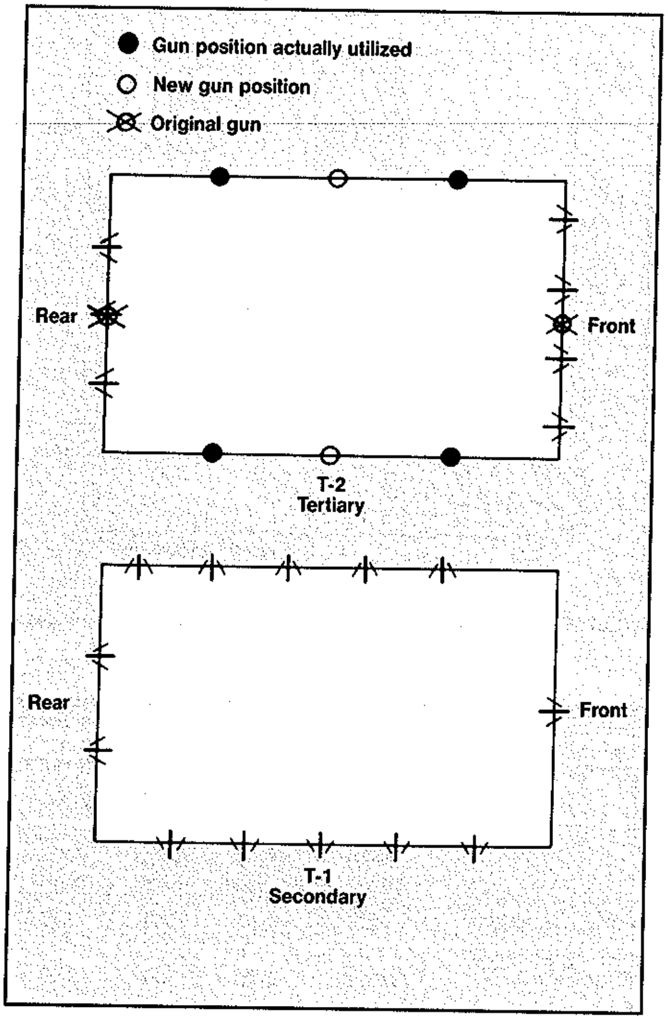
The location of tertiary ports on the front and rear walls provides a 90° shear relative to the secondary air ports, which are located on the side walls. This effect is useful in preventing the formation of a gaseous column from the bed.

Primary air system. Existing primary ports remain as per the model baseline, and they are spread evenly around the furnace periphery. Fourteen ports were added to cover the additional 7 ft created on each side wall when the front wall was moved forward. Fourteen new port rodders were added to the existing automated rodding system for the primary ports.

Fuel system. The higher solids of the fuel (70%) should require less wall dehydration, more direct bed firing, and lower atomization pressures. The new fuel and air system is illustrated in **Fig. 5.** The larger droplets (the result of lower atomization pressures) and reduced wall drying (with the associated entrainment that occurs when material breaks from the wall and drops to the bed) should reduce droplet carryover.

The combination-firing approach requires extra energy for fuel preparation and additional liquor guns to assure good bed coverage with low supply pressures. Six new stationary guns were installed to provide adequate coverage.

5. Upgraded fuel and air system



Convection-pass fouling

The second choke point was plugging of both the superheater and the generating bank with ash deposits. Plugging would force an eventual shutdown. The new design, which upgraded the combustion zone to improve mixing, also dictated that the superheater design should reflect the most conservative arrangements of clear side spacing, tube temperatures, and gas temperatures (all related to the fouling qualities of the fuel). In most cases, a low-odor conversion would not affect the superheater, but in this case, the superheater (a) was "underabsorbing" (736°F vs. 750°F final steam temperature); (b) would restrict outlet pressure because the pressure drop at the new steam capacity was insufficient; and (c) had demonstrated a loss of metal in the tubes. The replacement design utilized a three-flow approach (to stay within available limitations for drum working pressure) and increased the clear side spacing to inhibit fouling deposits from bridging. The replacement also permitted a shop-modularized design that minimized field welds and lifts. The superheater was shipped with headers attached.

The screen also was totally redesigned to utilize the screen superheater system as a tool to reduce gas-side temperatures prior to entering the closely spaced tubes in the generating bank. The combination of screen and superheater design will ensure (at the new design MCR) a gas temperature less than 1140°F entering the generating bank.

Steam circulation

Steam circulation was the third choke point. This was checked, and minor modifications were prescribed. Risers and supplies had to be added to the screen circuits, and additional steam-drum internals were required to assure that underflow guidelines were met. The addition of water-coil air preheaters (economizer water prior to going to the steam drum was utilized to heat the secondary- and primary-zone combustion air) provided adequate subcooling margin requirements to prevent steaming at the upgraded capacity.

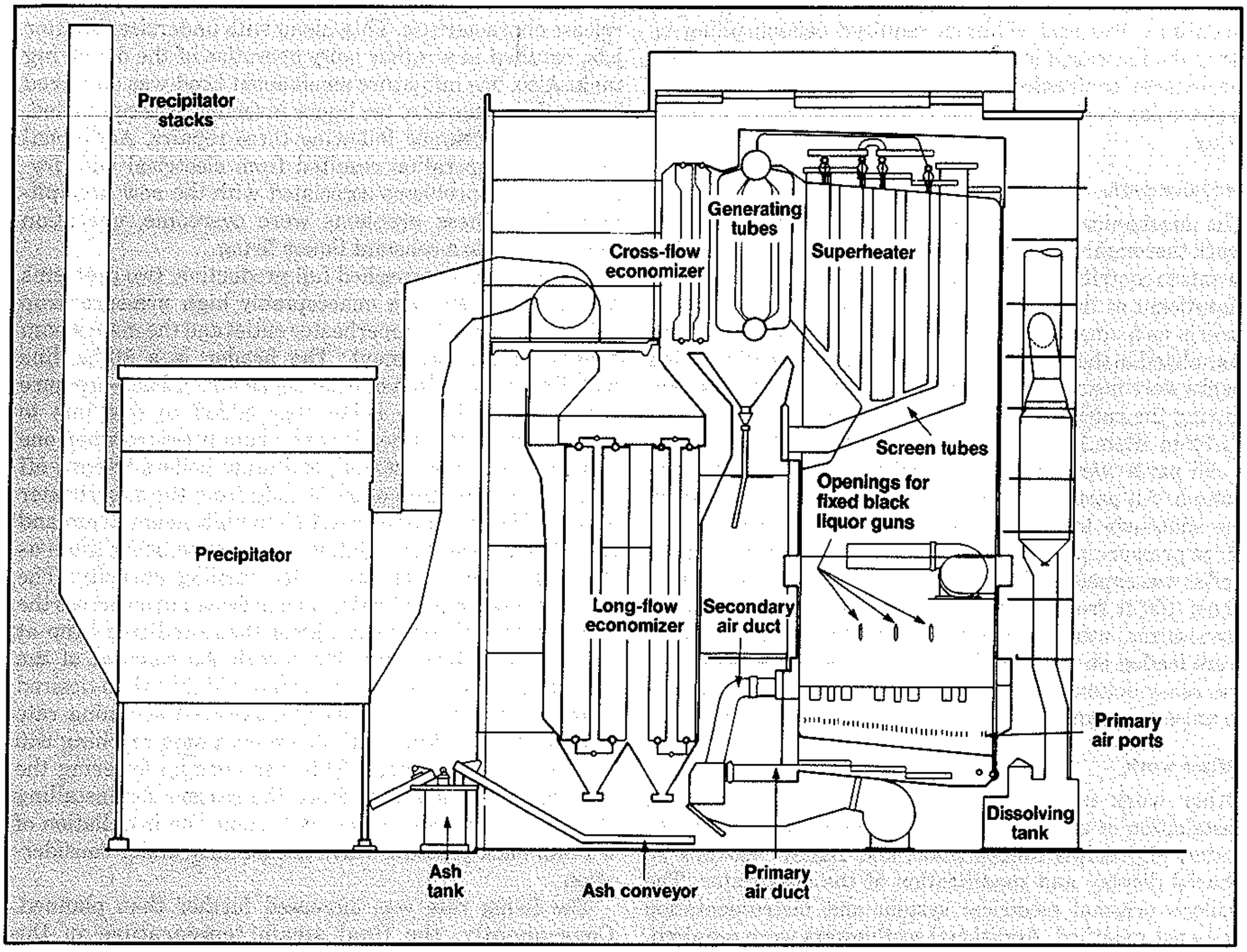
Construction

The rebuilt boiler is illustrated in **Fig. 6.** The increased production capacity and the low-odor conversion required installation of a high-solids concentrator, modifications to the evaporators, and installation of a Bailey Controls Network 90® shared display for control. A new Research–Cottrell dry-bottom precipitator (with required support auxiliaries) also was installed.

The project was finished within budget and seven days ahead of schedule. The boiler vendor was able to quickly determine its pressure-part needs based upon recent experience and model testing. Using this information and structural loads, the project engineer (Harris Group) proceeded to detail the scope of the construction necessary to support the pressure-part changes. The mill's goal was to minimize boiler outage time and reduce the cost of lost production. Based on results from a previous project (Wauna, Ore.) that was nearly the same in scope, a target shutdown of 56 days was selected. A monetary incentive was built into the erection contract to reward reduction of the outage period.

All work contracts were awarded based on competitive bids. Two mechanical contracts were required in the boiler area: (a) the pressure-part work and (b) all other

6. Boiler design after rebuild



mechanical and structural work. The pressure-part work was awarded to B&W as part of the overall equipment contract. The second contract was awarded to Sunland Construction of Houston. (Sunland is the nonunion construction arm of McDermott, B&W's parent company.) Sunland was also contracted to do the pressure-part work. With a single mechanical contractor doing all the work in and around the boiler building, scheduling and work conflicts were held to a minimum. This also provided an environment for finding ways to shorten the schedule.

The mechanical contractor moved onto the site Nov. 16, 1987. The boiler shutdown began March 13, 1988—two weeks ahead of schedule—because of a leak in a generating-section tube, which led to a subsequent emergency shutdown. This event added five days to the target shutdown time. The contractor worked two 12-h shifts, six days per week, with Sundays the primary X-ray day. Other X-ray work was accomplished during special night shifts. The unit was back on black liquor by May 12, 1988—a total of 60 down days.

Structural steel

The boiler columns were lengthened to accommodate the 9-ft increase in height. Perimeter steel was added to the boiler columns to support the steel grid supporting the new boiler. In general, the building steel was satisfactory and required stiffening only to carry the additional load of the added water walls, changes to the screen and superheater, and the new extended economizer. Most interior columns were stiffened with cover plates on the flanges. The rear building columns supporting the long-flow economizer required the most work. A small penthouse was required on the roof of the boiler building in the area of the main boiler columns because of the added height. One additional floor was required to provide access to the steam drum. This floor fit into the existing building without a change in roof level.

Foundations

Increasing the load-carrying capability of the foundations required well-thought-out construction methods. Analysis of the foundations, which were spread footings, showed most of them to be already overloaded. Therefore, to carry the added loads for the pressure-part changes, all the spread footings were expanded and tied together, forming a large single mat. Most of this work was completed before shutting down the boiler.

The ground floor of the building was excavated approximately 6 ft to expose all the footings. The footing extensions were doweled into the concrete of the existing footing. Only a portion of the top slab and the dissolving-tank foundation required completion during the boiler downtime. The rear columns required caisson piling to carry the increased load of the extended economizer. The mechanical contractor was able to complete all of the preparation work necessary to begin the shutdown without delay.

Pressure parts

The mechanical contractor planned the pressure-part work thoroughly and thus was able to identify time-saving events to contribute to the incentive award. One of the most significant of these was the installation of the waterwall panels as a single unit. The intermediate weld joint was completed in the laydown area and X-rayed. Special strong backs were installed on the panels to prevent over-bending during the raising process. More than 334 tube welds (2-21/32-in. diam.) were removed from the shutdown work.

All parts were installed by raising them up from the bottom. All parts were inspected and inventoried prior to the shutdown to identify any problems. Transfer of the large pressure-part modules from the laydown area to the boiler was expedited by using the mill's rail siding (located about 100 ft from the front of the boiler). The extended economizer, waterwall panels, superheater platens, etc., were loaded on flat cars before the outage and moved to the construction area when required. A crane was used to unload the equipment and place it within the building.

Other work

Other work related to the boiler upgrade included installation of electrical wiring, instrumentation, precipitator, high-solids concentrator, and Bailey Network 90 shared display and modification of the evaporator. The boiler's original electrical system and instrumentation were not modified. Additional sootblowers were required. These were added to the existing system, and a new sequencing program was written for the mill's solid-state controller. Certain field transmitters were replaced, and alarm and monitoring signals were added from the new precipitator. The new precipitator was moved into its final location at the back of the boiler during the shutdown after the old tile-shell unit was demolished.

These other construction activities were added to the master boiler/mechanical construction schedule, which was computer generated by the boiler vendor. Inputs were made in the field and printed on a mill printer on an as-needed basis.

The new high-solids concentrator and the evaporator modifications, as well as the Network 90 shared-display system to control and monitor them, were considered to be stand-alone projects. They were started up one month before the boiler shutdown to provide ample checkout time and operator training prior to the boiler work.

Startup: problems and performance

The newly rebuilt recovery boiler was started up on May 12, 1988. A high level of firing rate and uptime has been sustained since startup.

The fuel fired into the boiler during startup was heavily concentrated with spent synthetic liquor composed of slaked-soda-ash slurry and sodium hydrosulfide. During the first ten days to two weeks of firing, the ammonia-contaminated synthetic liquor gave the smelt a high heat-release characteristic. This, along with undersized shatter jets, resulted in a rather noisy operation of the dissolving tank. Also, one miniature smelt-spout hood was damaged before the turnover of the liquor inventory was completed. Firing was resumed following these repairs. Additional interrupted operation resulted from electrical and dry-ash-conveyor problems associated with the new precipitator. Once these problems were overcome, operation settled down to a constant liquor firing.

As the boiler approached full production, two problems became apparent. An unacceptably high pressure drop existed between the superheater outlet and the main steam header in the basement. The header is a 10-in. line handling 371,000 lb/h of 600-psig steam. A back-pressure control valve to the boiler was added to this line to minimize the loss of header and drum pressure when one or both of the other steam-generating boilers tripped off line. A pressure drop of 50–60 psig from the superheater outlet to the mill header resulted in high steam-drum and superheater pressures. Safety valves were being lifted as the boiler was loaded up to its burning capacity. The pressure readings indicated a near-design drop across the superheater section but a higher-than-predicted drop at the back-pressure valve. Even with the removal of the valve internals (stem and butterfly), a higher-than-desired pressure drop to the header still exists. A steaming rate of up to 400,000 lb/h (with drum pressures reaching 640 psig) has been achieved. This was done by lowering the mill header to 550 psig. Since the reasons for installing the back-pressure valve are still valid, the installation of a 14-in. back-pressure valve is currently under consideration.

The firing rate was increased further than planned. Consequently, the final steam temperature in the superheater increased above the planned 750°F discharge temperature. Thermocouple readings of individual secondary-superheater tube-metal temperature exceeded 850°F. While the outlet steam temperature did not exceed this level, the firing rate had to be restricted to approximately 90% of design capacity to stay within individual tube-metal temperature limitations. Normal "seasoning" of the superheater surface would act to reduce absorptions over time, but the air-flow upgrade stretched this "fouling" period out to several months. The air distribution was varied to improve the temperature gradient through the superheaters, and the solids were lowered from 70–72% down to 66–68%. A modest improvement was achieved with these changes. In an effort to retard heat absorption, the sootblowers were not blown in the superheater section for the first several months of operation. As the superheater began to "season" (foul) with salt-cake accumulation, the temperature, as expected, fell off. At this time, IK blowing was resumed. The thermocouples on the superheater tubes were set to alarm at 825°F. Operators would act to restrict liquor flow if the temperature exceeded 850°F.

Four months after startup, options to increase the firing rate were considered and included the following:

- Add additional screen tubes to absorb heat ahead of the superheater.
- Add an attemperator.

II. Predicted vs. actual performance of rebuilt recovery unit

	Predicted	*Actual*	*Superheater surface removal (actual)*
Steam flow, 10^3 lb/h	369	378	325–350
Liquor solids, 10^3 lb/h	113 (virgin)	118 (with recycle)	116 (with recycle)
Excess air, %	15	1.8	1–3
Total heat, 10^6 Btu/h	693.9	710	665
Steam pressure, lb/in.^{2}	600	583	560
Pressure drop (drum to superheater outlet), lb/in.^{2}	37.4	32	...
Flue gas leaving boiler, °F	803	756	...
Flue gas leaving economizer, °F	365	360	360
Air to water coil, °F	95	90	90
Water to economizer, °F	306	300	300
Liquor to furnace, °F	220	258	260–265
Solids, %	70	72	72
Heat to steam, %	64.77	...	...
TRS, ppm (at 8% O_2)	...	2.9	...
Reduction, %	...	96–98	96–98

III. Performance history

	Original design	*Before rebuild*	*After rebuild*	*Percent increase over "before rebuild"*	*Percent increase over "original design"*
Unit size, tons	600	670	820	22	37
Liquor solids, 10^6 lb/day	1.8	2.2	2.7	23	50
Steam flow, 10^3 lb/h	275	275	407	47	47
Liquor heating valve, Btu/lb•h	6600	6026	6026	...	...
Solids to furnace, %	66	65	70	7.8	...
Pulp production, a.d. unbleached tons/day	...	591	733	24	...

- Remove superheater surface area.
- Make an IK steam header connection between the primary and secondary superheater sections and utilize superheater steam for sootblowing. This in turn would increase the quantity of steam flowing through the primary superheater and reduce metal temperatures. The IKs have for the most part been run on saturated steam directly from the drum.

It was decided to pursue the last two options during the semiannual shutdown, which began a little over five months after startup. The removal of the superheater tubes was engineered and carried out by B&W within a seven-day liquor-to-liquor outage. The design changes significantly reduced the temperature of the superheater tubes. After evaluating the use of superheated steam for sootblowing over a six-week period, we reverted to saturated steam. However, the use of superheated IK steam was essential (increasing the steam mass flow) to reducing the temperature of the superheater tubes during the early post-restart period. These changes permitted operating rates up 828 tons/day vs. the design rate of 820 tons/day. While the addition of an attemperator was once considered to be a likely followup measure, its application is no longer considered. All boiler components appear to be a good match for the designed steaming and circulation rates. No further changes are contemplated.

A review of the recovery boiler startup would be incomplete without a discussion of liquor-firing experience. The premodified boiler was fired with two conventional oscillating liquor guns. One gun was stationary-fired on the back wall with a size-28 nozzle and a 52° splash plate. A second gun with a size-36 nozzle and a 52° splash plate was oscillated on the front wall. Firing liquor was 62–66% solids at 220–230°F, with 30–40-psig nozzle pressure. This method of firing had proven satisfactory on the old boiler. Firing of the modified boiler was started at much the same condition. The major exception was the higher liquor solids of 70–72%. The new concentrators had been started up a few weeks ahead of the boiler rebuild. Liquor temperature was varied between 230°F and 260°F. After seven weeks of sustained operation, stationary firing was started.

Initially, six guns with size-36 nozzles and 35° splash plates were fired from the side walls. Gun angle, nozzle size, and placement were varied. Four guns with size-38 nozzles were evaluated, one gun on each wall. The most successful configuration proved to be the size-38 nozzle using four guns located on the two outside positions on each side wall, the gun angled just a few degrees below the horizontal, solids 70–72%, temperature 260–262°F and a nozzle pressure 16–20 psig. At a lower pressure, the temperatures must be reduced to prevent flashing of the liquor in lines and nozzles. The low-odor configuration and stationary firing have resulted in hotter-burning liquor temperatures, lower TRS emissions (less than 3 ppm), fewer smelt-spout plugging problems, no blackout problems, less carryover in the boiler, and reduced plugging, resulting in semiannual boiler water washes.

Several small problems have surfaced in connection with the stationary firing. The higher furnace temperatures and reduced heat removal with the hotter fired liquor has caused several nozzles and pipe nipples behind the nozzles to burn and erode. This problem was corrected by shortening the nipples and going to a heavier-schedule pipe. The nozzles are now inspected and washed out on a routine rotating basis.

The hotter bed and the higher-solids liquor generally combine to produce a tendency toward lower TRS emissions but slightly higher NO_x levels than those measured in older non-low-odor units. The recovery boiler PSD (prevention of significant deterioration) stack permit is being resubmitted for a somewhat higher rating for the NO_x.

All of the startup problems have been or are being resolved, with one exception. The long-flow economizers have two cross-chain conveyors that drop salt-cake ash through an air lock on each drag to another traverse chain conveyor. The larger conveyor carries the ash to the precipitator ash mix tank. The chains, flights, sprockets, and air-lock shafts have been a source of continuous mechanical problems. Analyses indicated the chain permitted the flight bars to rotate when "lumps" were being conveyed, which in turn displayed the chain and permitted it to jump the sprocket. The chain has been replaced with a rigid flight connector, which should correct this problem. In the future, heavier-duty equipment will be specified for similar service requirements.

Measured performance closely matches predicted performance, as seen in **Table II**. The performance of the recovery unit before and after the rebuild is given in **Table III**.□

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