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The Supercritical Recirculation Boiler Start-Up and Operation

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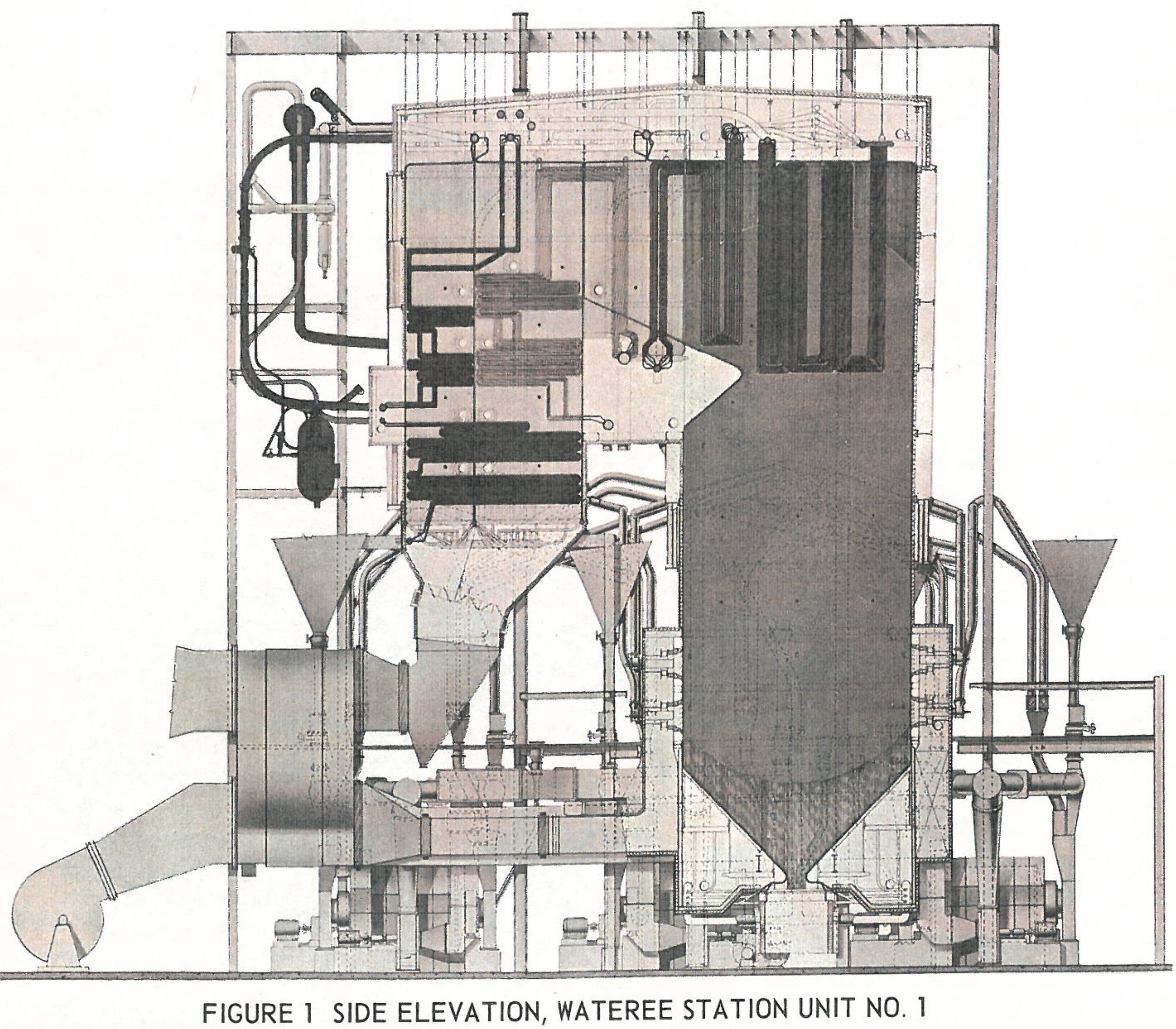

FIGURE 1 SIDE ELEVATION, WATEREE STATION UNIT NO. 1

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START-UP AND OPERATION

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INTRODUCTION

In the American Power Conference Proceedings of 1967, a paper entitled "The Supercritical Recirculation Boiler" was presented by Mr. H. H. Hemenway and Mr. T. F. Walsh of Riley Stoker Corporation (Reference 1.). In this paper a pre-operational report was given outlining the general design philosophy and specific objectives of this new type of supercritical pressure steam generator. The purpose of the present paper is to provide the continuation and report the actual operational experience of Unit No. 1 of the South Carolina Electric and Gas Company's station at Columbia, South Carolina. Unit No. 2, a duplicate unit presently under construction will go into commercial operation in the Fall of 1971.

GENERAL BOILER DESIGN

The general boiler design is shown in Figure 1, a sectional side elevation of Unit No. 1. This arrangement shows the once-through supercritical pressure recirculation boiler. The boiler is fired with pulverized coal and operates with balanced draft. The maximum continuous capacity is 2,846,000 lbs/hr of 1005°F steam at 3735 psig at the superheater outlet. The reheater flow is 2,262,000 lbs/hr at 1005°F at the reheater outlet. The unit serves a General Electric steam turbine generator unit with a maximum output of 403 MW.

The firing equipment consists of three Riley ball tube mills supplying pulverized coal to twenty-four Riley flare-type coal burners arranged opposed in the front and rear walls of the furnace. The coal mills and burners are controlled by a Bailey Meter Company '760' burner control system. The boiler is controlled by a Bailey Meter Company '721' analog control system. The boiler convection section consists of a conventional two gas pass arrangement with reheat control by gas proportioning. The main steam temperature is controlled by firing rate. A steady state spray of 4% of feed rate is employed and may be increased or decreased to trim peaks and valleys. There are two Ljungstrom type horizontal shaft air preheaters. Air and gas streams are handled by two airfoil type forced draft fans and two induced draft fans.

The unit, designed for a low setting, is 144 feet to the top of the steel. The entire gas passage enclosure from the furnace to the economizer outlet is of welded tube and fin construction and is gas tight. The furnace is 60'-6" wide and 36'-0" deep.

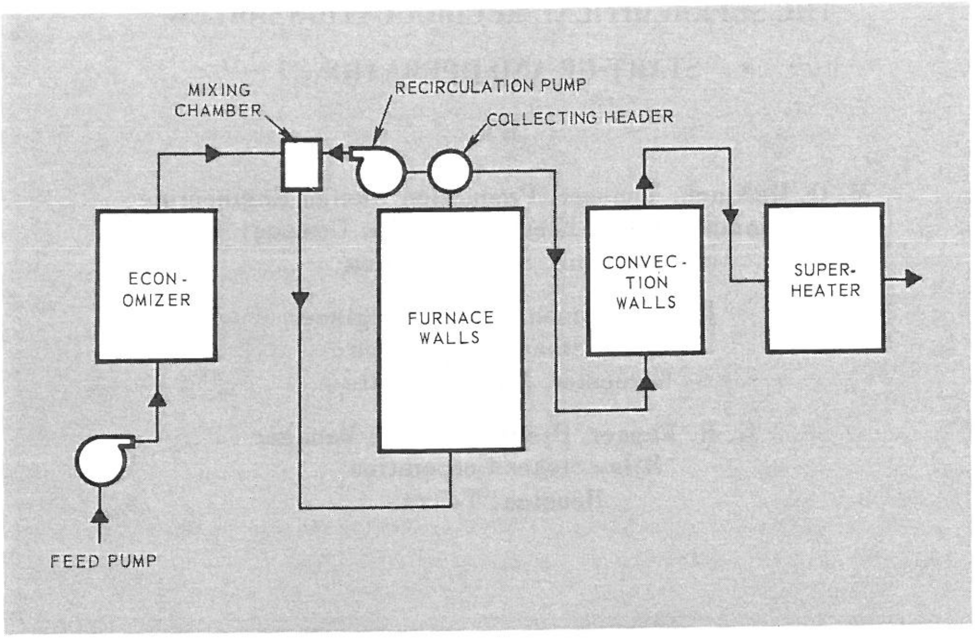

FIGURE 2 FLOW DIAGRAM FOR RECIRCULATION BOILER

GENERAL DESIGN OF THE RECIRCULATION SYSTEM

The basic circuit of the recirculation type boiler is shown in Figure 2. A collection header receives the entire flow out of the four walls of the furnace. The flow divides from this junction or collecting header to the recirculation loop with the other path continuing as through flow to the convection walls of the rear convection pass and from there to the superheater. The release into the collecting header from the furnace walls is preferentially routed to collect the cooler fluid from the furnace corners into the two ends of the collecting header. It is from these positions that the recirculation fluid is withdrawn. The intent is to recirculate cooler fluid to capitalize on the highest possible fluid density to the downcomer and the pump.

The recirculation pumping system consists of two 100% canned, motor driven centrifugal pumps with one on hot stand by and capable of being placed on the line in 0.9 seconds. Since the recirculation pumps are not required at loads higher than 90%, the unit will not be tripped if these pumps are lost at this load or higher. The pump that is in service operates continuously at all loads and discharges furnace fluid into the mixing chamber where the recirculated fluid mixes with feedwater leaving the economizer. The mixing chamber is mounted at the highest practical elevation to take full advantage of gravitational head to augment the pumping head of the recirculation pump. The recirculation pump operates in parallel with the main boiler feed pump, and thus handles only recirculated fluid rather than a combination of recirculated and through flow that would be required by a series located pump.

The actual on line recirculation pump power is approximately 100 horsepower. Because the specific volume of the furnace fluid during a cold start is substantially less than the specific volume at normal operating temperature, the pump motor selection must be sized for the cold start condition, which is approximately six times the power required for normal operating conditions.

Flow from the single mixing chamber continues through two downcomers, one to each side of the furnace bottom. There are twenty-six panels of approximately 51 tubes each comprising the four perimeter walls of the furnace. The flow from the two downcomers divides into separate feeders to the inlet headers of the panels. The fluid makes one pass up through all 1326 tubes contained in the 26 panels. The discharge into the collecting header is direct from the panels or through releaser pipes from outlet headers.

In Wateree Unit No. 1, complete instrumentation, thermocouples, and laboratory calibrated double impact pitot tubes were installed in the two downcomers and the 26 feeder pipes to establish the means for determining the flow to each panel. Also, 380 thermocouples were installed at six elevations on all four walls to measure bulk, tube crown, and fin temperatures. It was felt that with this instrumentation sufficient field data could be gathered to generate a corrective program of orificing if such a requirement arose.

To analyze the need for initial orificing it was necessary to develop a comprehensive computer program. When this computer program became operational, studies were made to determine the influence of load, excess air, heat input, and other variables. As a result of the many checks made of the design, the final analysis indicated that no orificing was required in either the feeder pipes or individual tubes. The actual operations of this boiler has corroborated the analysis.

START-UP EXPERIENCE

HYDROSTATIC TEST

The first pressure test applied to the unit was 150 psig of air which located seven furnace wall leaks and one superheater leak. Next, a 1000 psig hydro was applied and indicated one more furnace wall leak. The final hydro exposed three more furnace wall leaks. Hydrostatic testing produced, therefore, a total of eleven leaks:

five in drilled holes for furnace wall thermocouples,

four in furnace wall membrane welds,

one in furnace wall membrane welds, and

one in radiant superheater tube shop weld.

PRE-OPERATION CLEAN-UP

An alkaline flush was performed first on the preboiler cycle and then the boiler system through the economizer, furnace walls, convection walls, recirculating pump arrangement and start-up drum. This was followed by cleaning with 3% hydroxy acetic acid with inhibitor at 200° F through the preboiler cycle, economizer, furnace, and convection walls. The recirculating pumps, superheater, and reheater were isolated from acid cleaning. Steam for line blowing of the superheater, reheater, and plant piping was supplied by the boiler from the start-up drum with the start-up (SU1) valves, Figure 3, automatically holding 3500 psig on the boiler. The boiler was fired at as high a rate as reheater metal or fuel limitations would permit. Down stream line pressure for blowing the superheater and reheater was regulated by the use of the SU2 valve (Figure 3).

HOT CLEAN-UP

The boiler was pressurized to about 200 psig up to the inlet of the start-up drum (SU1 valves) and then a recirculating pump was started causing a flow from the mixing chamber through the furnace to the rear convection pass into the pump and back to the mixing chamber. Recirculation flow at this low temperature was approximately 3,000,000 pounds per hour. The light oil warm-up guns were fired to increase pressure and temperature to 3500 psi and 450°F. A nominal feedwater rate was started at 400°F and the flow rate was increased to approximately 20% at 450° F to expedite the hot clean-up process. The boiler was held at this condition until a 250 ppb millipore filter sample was obtained. Furnace fluid temperature was then increased to 550° F and another sample was tested for a maximum of 250 ppb solids.

Desirable feedwater quality before increasing furnace fluid temperature to 755°F for turbine synchronization of this copper-free system was:

Total Solids	-	250 ppb
Iron	-	50 ppb
Silica	-	30 ppb
Oxygen	-	10 ppb

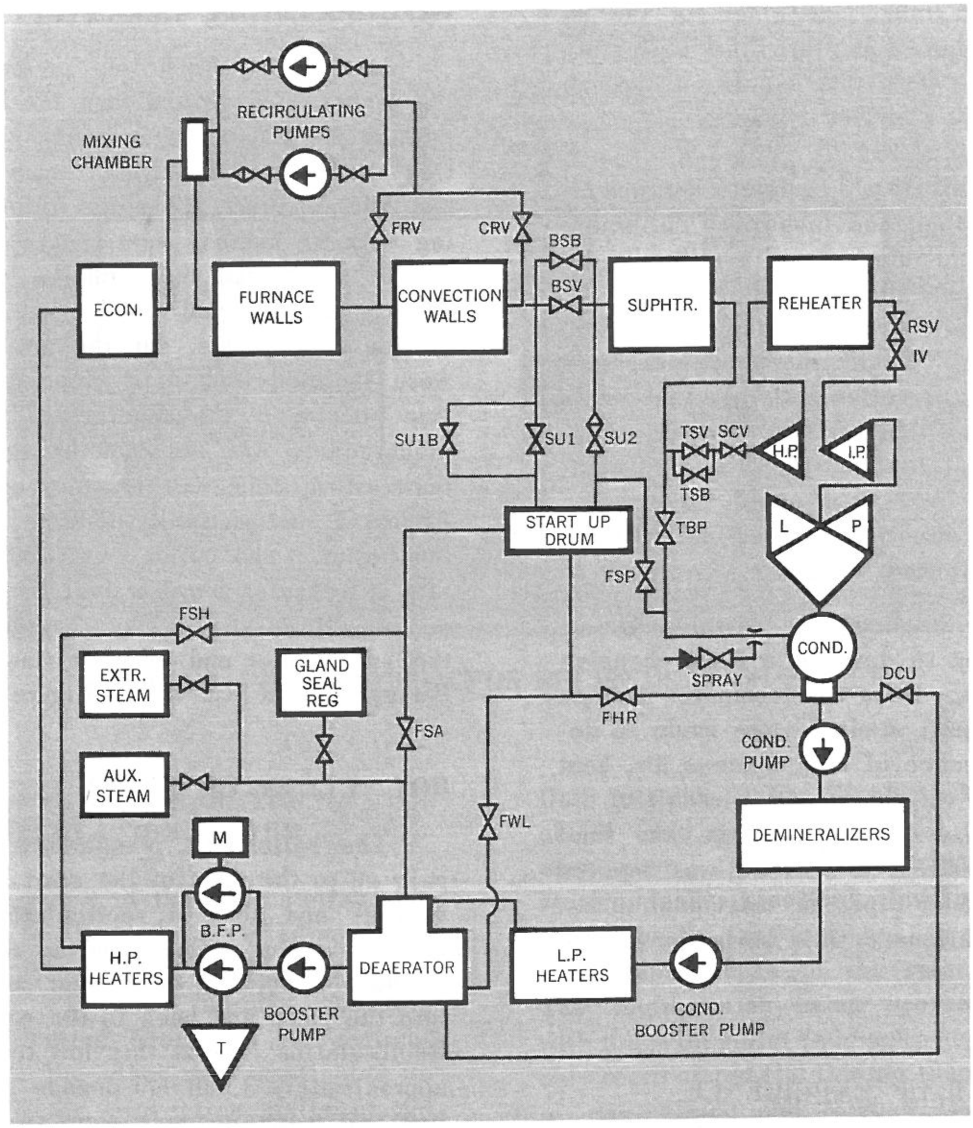

FIGURE 3 PLANT START-UP SYSTEM

Eventual feedwater limits held by South Carolina Electric and Gas under normal operating conditions are:

Cation Conductivity	-	0.5 MMno
Total Iron	-	10 ppb
Total Silica	-	10 ppb
Oxygen	-	10 ppb
PH	-	9.5-9.7 ppb

SYNCHRONIZATION

The Riley system uses the boiler recirculation pump to eliminate a strict minimum through flow. Automatic control of oil firing by transverse furnace probes protects the superheater at low flows. At the conclusion of hot clean-up the start-up drum pressure was ramped to 2000 psig, as a function of furnace fluid temperature, by turbine by-pass (T B P) valves. Boiler pressure above 400°F was controlled at 3500 psig by the start-up drum (SU 1) valves. Feedwater flow and firing rate were adjusted to obtain a final 755°F boiler fluid temperature together with a desired final superheat temperature. The 2000 psig start-up system was provided to permit lower furnace fluid outlet enthalpy (1135) at transfer conditions with consequent reduced firing rate and superheat temperature. The lower attendant furnace fluid temperature and specific volume provide added margin against furnace tube failure by decreased metal temperature and increased circulation.

The turbine was synchronized at 2000 psig and transferred to through flow at about 20% load. The time required to transfer from the SU1 valves to the through flow BSB valves was (after a number of operations) considered best at two minutes, although it can be accomplished in five seconds. Returning to the start-up drum before transfer is completed is easily accomplished. Continued load increase ramps the superheater pressure to 3500 psig by coordinated control of the turbine valves. When the superheater pressure has increased to approximately 3200 psi the BSB valves will be about 80% open. This opening generates a signal which pulses the BSV valves. When these latter valves reach a 50% open position they are automatically run to a wide open position.

ON LINE PERFORMANCE

Operating the unit manually while the controls were being tuned was a difficult procedure. Small changes in furnace fluid outlet temperature caused large changes in final superheater temperature. Precise control of furnace temperature had to be exercised to maintain acceptable superheat temperature in order to protect the turbine. When the superheater was below supercritical pressure, "going wet" through the BSB valves caused a sharp drop in final steam temperature and necessitated several trips for turbine protection.

Considerable time was necessary to complete satisfactory control tuning, but when this was achieved, operation to date indicates the following:

The boiler meets or exceeds the guaranteed boiler efficiency.

The superheater temperature meets the guaranteed control range from control point (40%) to full load. The reheater temperature meets the guaranteed control load range from control point (50%) to full load.

The guaranteed pressure drop from the economizer inlet to the superheater outlet at 2,567,000 pounds per hour is 320 psi. The actual pressure drop at this load is 75 psi below the guaranteed value.

Pressure drops and draft losses on the air and gas sides are also within guarantees.

FIRESIDE PERFORMANCE

Slagging has never been a problem in this boiler. This is quite significant when consideration is given to the fact that the coal supplied to this boiler comes from an average of 14 different mines during a month and at times consists of blends of any or all of these coals. Blending of these coals may cause ash fusion temperatures substantially lower than individual coals. During one two week period, a small accumulation of ash occured on the upper slope of the deflector arch. The retractable blowers in this vicinity were out of service due to bent lance tubes. After straightening and enlargement of the orifice in the plug, per blower manufacturer's recommendation, the ash accumulation on the arch was removed by soot blower operation.

At times boiler capability is limited by fuel quality because of substantial departure from specified fuel resulting in reduced mill capacity. Coals were specified for fuel burning equipment selection on the basis of 55 Hardgrove grindability. There have been instances where the actual grindability has dropped to values below 40.0, which seriously reduced mill capacity.

Figure 4 is a plot of furnace fluid temperature, actual and predicted, at a point near full load. It will be noted that the peaking of heat input assumed at the center of each wall did not occur. Other tests were run to determine the influence of load and other variables. There was no indication of flow instability at any time.

The final design decision was made to employ 1-1/8" O.D., SA-213 T-11 (1-1/4 chrome) tubing and fins. As mentioned previously, the heat absorption patterns were

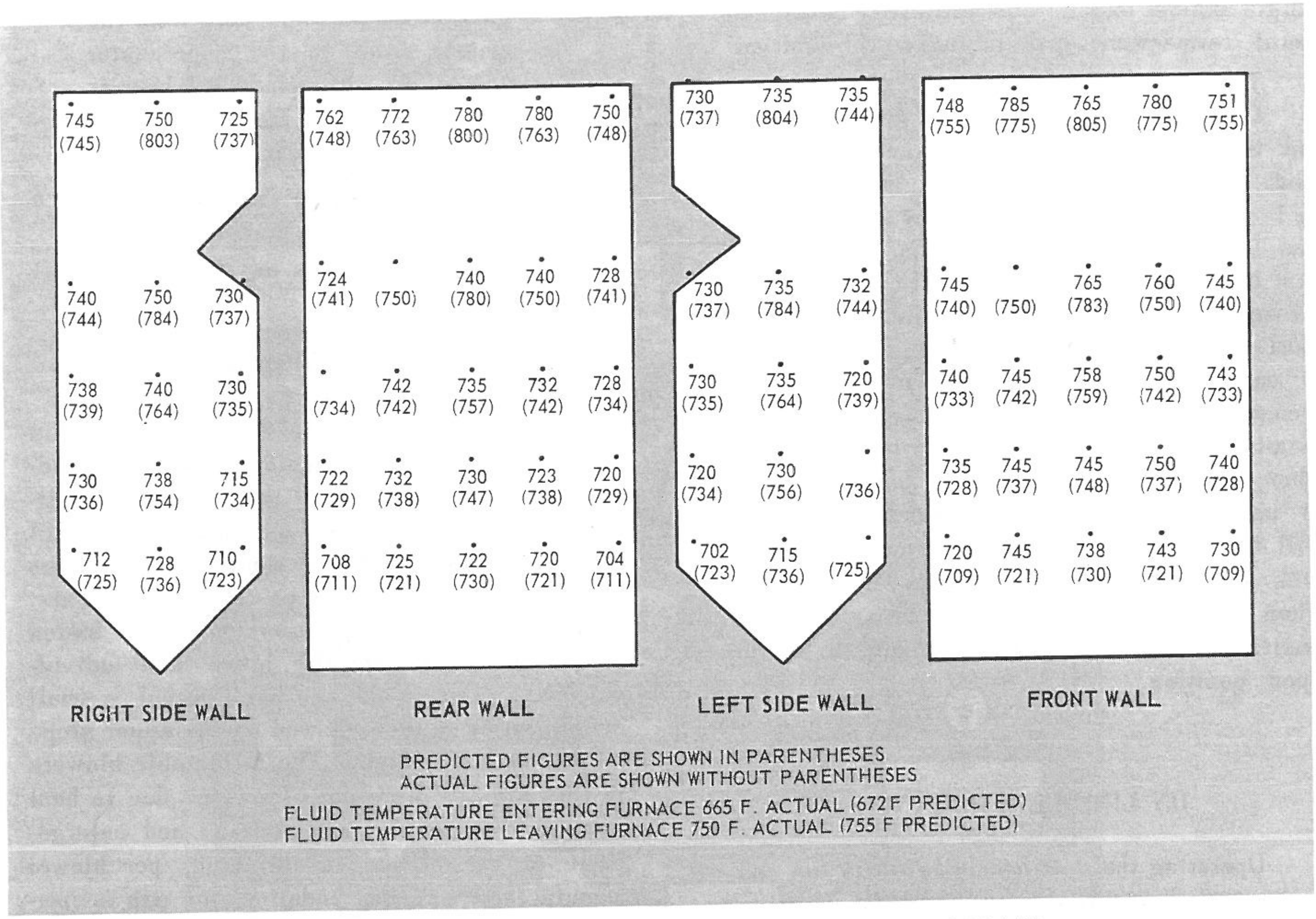

FIGURE 4 FURNACE FLUID TEMPERATURES AT 375 MW

substantially less severe than predicted. It was estimated that the highest crown temperature of 1025°F at full load would occur at the center of front wall. Actual thermocouple readings indicate that the maximum recorded crown or outer skin temperature is about 100°F lower than this value throughout the entire furnace.

The actual fluid temperature and recirculation performance versus load is shown in Figure 5. It will be noted that the furnace outlet, furnace inlet, and the economizer outlet temperature deviate from the predicted values as a result of feedwater heaters being out of service. With the predicted feedwater temperature to the economizer, the economizer outlet and the furnace temperatures would be very close to the predicted values. In the bottom of Figure 5, recirculation performance is indicated. The increase above prediction of the recirculation flow in actual operation is the result of conservatism in the design of the entire recirculation system.

OPERATING PROBLEMS

Feedwater for the unit is supplied by two 50% capacity turbine driven and one 30% capacity motor driven feedwater pumps. Advantage was taken of the boilers ability to operate with zero feedwater rate to avoid low temperature high pressure breakdown service by the start-up (SU 1) valves by firing without feedwater until the furnace fluid temperature reaches 400°F. No cavitation problems were encountered in the start-up system valves. Initial pre-operation plans called for using the full pressure motor driven pump for unit start-up. Ironically the motor driven pump was not available for initial start-up and the turbine driven pumps were successfully substituted.

Copes pneumatic driven start-up valves from an electronic control signal were pre-operationally checked out by their service engineer. Air supply lines to the diaphragms on the start-up drum (SU 1) valves and boiler to superheater (B S B) valves were increased in size to give quicker response. The cage of the SU 1 valves was modified after pounding of one valve, caused by dirt on the positioner, broke a valve seat flange into a number of pieces which in turn lodged in other level control valves for the start-up drum.

Anti-Resonant baffles had to be installed in the superheater convection pass to eliminate a flow induced pulsation.

Thirteen leaks were found during hot clean ups or re-starts:

- ten in furnace membrane welds,
- one in furnace tubes shop butt weld,
- one in furnace tube field butt weld, and
- one in furnace tube caused by expansion strain.

Pre-commercial operation experienced twenty-five unit trips:

- sixteen caused by controls,
- three caused by turbine vibration,
- three caused by wiring errors,
- one caused by auxiliary boiler equipment,
- one caused by main boiler tube failure, and
- one unknown.

Post-commercial operation experienced five unit trips as of March 15, 1971:

- three caused by power failures, and
- two caused by controls.

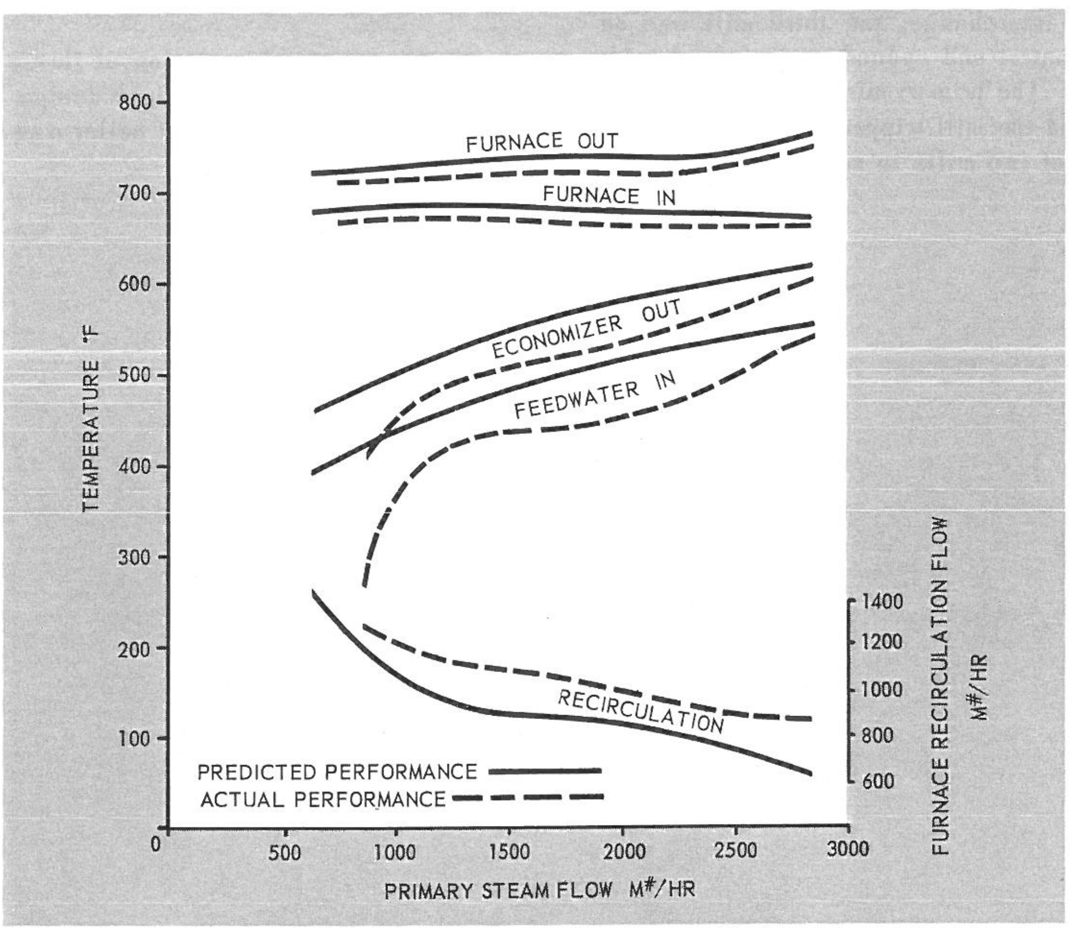

FIGURE 5 FLUID TEMPERATURE AND RECIRCULATION PERFORMANCE VS. LOAD

There have been no unit trips caused by boiler malfunctions. There have been six forced outages accountable to the boiler. Two outages were caused by tube leaks, one in a field weld and the other tube leak apparently caused by two gross temperature excursions. The other four outages were caused by boiler controls.

During the first excursion, which lasted approximately 25 minutes, the furnace outlet fluid temperature peaked at 1015°F. The second excursion, which lasted 15 minutes, the temperature peak was 955°F. The tube failure consisted of a small crack in the fin-to-tube weld area. Subsequent examination showed that this shop weld was defective. These temperature excursions occured when the heat input to the boiler was reduced 50% by loss of one of the two mills in service. Loss of the mill occured when the primary air fan motor tripped due to an overload. The first occurrence was caused simply by overloading a mill. The second upset occured when attempting to put a mill in service while removing another mill. During this interchange, the third mill was on automatic control and opened up to furnish additional fuel. The primary air fan capability was exceeded and the mill tripped. With the sudden loss of one of two mills in service, the quantity of extraction steam for feed pump power becomes inadequate and a severe reduction in feedwater flow results. Because the remaining mill was on manual control, it could not follow feedwater flow and a temperature excursion resulted. The ability of the unit to withstand these excursions confirms the substantial flow stability of the recirculation boiler.

Since these occurrences, a limit on air flow from these primary air fans has been established to prevent such overload trips. This air flow is measured by the classifier-to-furnace differential.

AVAILABILITY

The forced outages and unit trips caused by malfunctions of the boiler proper have been minimal. Boiler availability during commercial operation was 98.5% September 10, 1970 through March 15, 1971

CONCLUSION

Start-up and operation of this unit to date has proven that the original design philosophy used for this supercritical boiler was completely sound.

LIST OF REFERENCES

1. - The Supercritical Recirculation Boiler

H. H. Hemenway
T. F. Walsh

The American Power Conference 1967