PULVERIZED COAL BOILER OPTIMIZATION THROUGH FUEL/AIR CONTROL

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1.0 <u>BACKGROUND AND DESCRIPTION OF UNIT</u>

The W. C. Beckjord Unit No. 6 is a nominal 440 Mw pulverized coal fueled unit. The steam generator is a four corner, corner fired boiler designed by Combustion Engineering Company. Pertinent design data for the boiler are shown on Figures 1 through 3.

CROSS-SECTION OF WCBS #6 STEAM GENERATOR

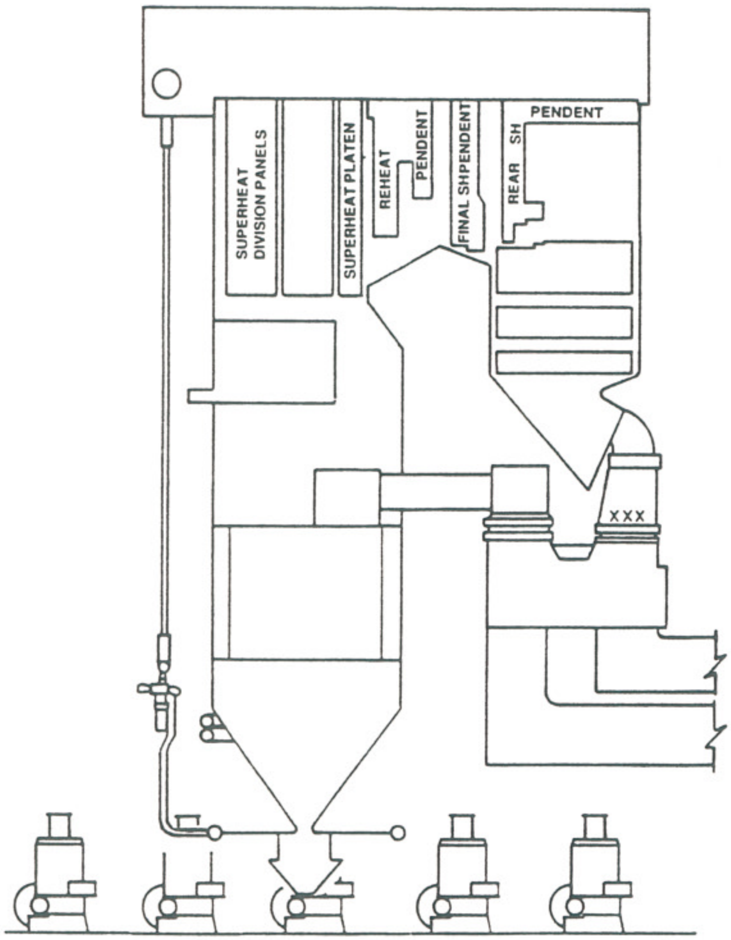


FIGURE 1

Furnace Volume	- 274,000 Ft.^{3}
Pulverizers	- 5 Raymond #823
Burners	- 20
Design Fuel	- 59 HGI / 11.9% Ash / 11,000 BTU/# / 10% Moisture
Ash Fusion	- 2,000°F

FIGURE 2

STEAM EVAPORATION RATE				
	Units	Control Point	Maximum Continuous Rating	Peak
Steam Evaporation Rate	#/HR.	1,710,000	2,850,000	3,150,000
Main Steam Temperature	°F	1005	1005	1005
Reheat Steam Temperature	°F	1005	1005	1005
Feedwater Temperature	°F	428	476	486
Flue Gas Lug. Air Heater	°F	256	270	272
Overall Efficiency	%	89.95	89.10	89.01

FIGURE 3

The boiler contract was let in 1964, and the boiler went into operation in the late 60's as a pressurized furnace. Since initial operation the steam generator had not been performing to design expectations. Over the years a number of modifications were made to the boiler. Among the changes were the following:

1) One loop of the low temperature superheater horizontal surface was removed. This was done during erection of the unit, and the surface removed was about 16,600 $Ft.^2$

2) The front reheat pendant section was shortened approximately eight feet. The surface removed was about 5,300 $Ft.^2$

3) A rear wall hanger tube refractory baffle was installed to eliminate the possibility of flue gas bypassing the shortened front reheat pendant.

4) Following initial operation of the unit, and to reduce excessive superheating spray flows, portions of the 31 superheater platen assemblies were removed. This was approximately 5,620 $Ft.^2$ of surface, and was removed about 1970.

5) 1974 - The unshaded portion of the reheat radiant sidewalls below the S.H. division panels was removed. This surface had experienced cracking, and the surface removed totaled about 1,850 $Ft.^2$

6) 1975 - The unit was converted to balanced draft.

7) 1982 - The original continuous fin economizer surface was replaced with a spiral fin, in-line economizer.

8) 1984 - An additional 6,600 $Ft.^2$ of reheat surface was added to the pendant surface, and ten LTSH assemblies were replaced.

9) 1985 - A portion of the lower refractory wall was removed to reduce reheat spray water usage.

10) 1987 - Concentric firing, or offset air nozzles were installed in an attempt to reduce slagging and to improve waterwall heat transfer, thus reducing reheat sprays. Also, removed portions of the top and bottom of the refractory wall to bypass R.H. surface and reduce the reheater - desuperheating spray water requirements.

11) 1988 - Completed a Comprehensive Diagnostic Test to identify opportunities for combustion optimization, and to design changes.

12) 1989 - Completed Combustion Optimization through improved fuel and combustion air flow control.

2.0 DESCRIPTION OF THE COMPREHENSIVE DIAGNOSTIC TESTING AND OPPORTUNITIES FOR IMPROVEMENT THAT WERE IDENTIFIED

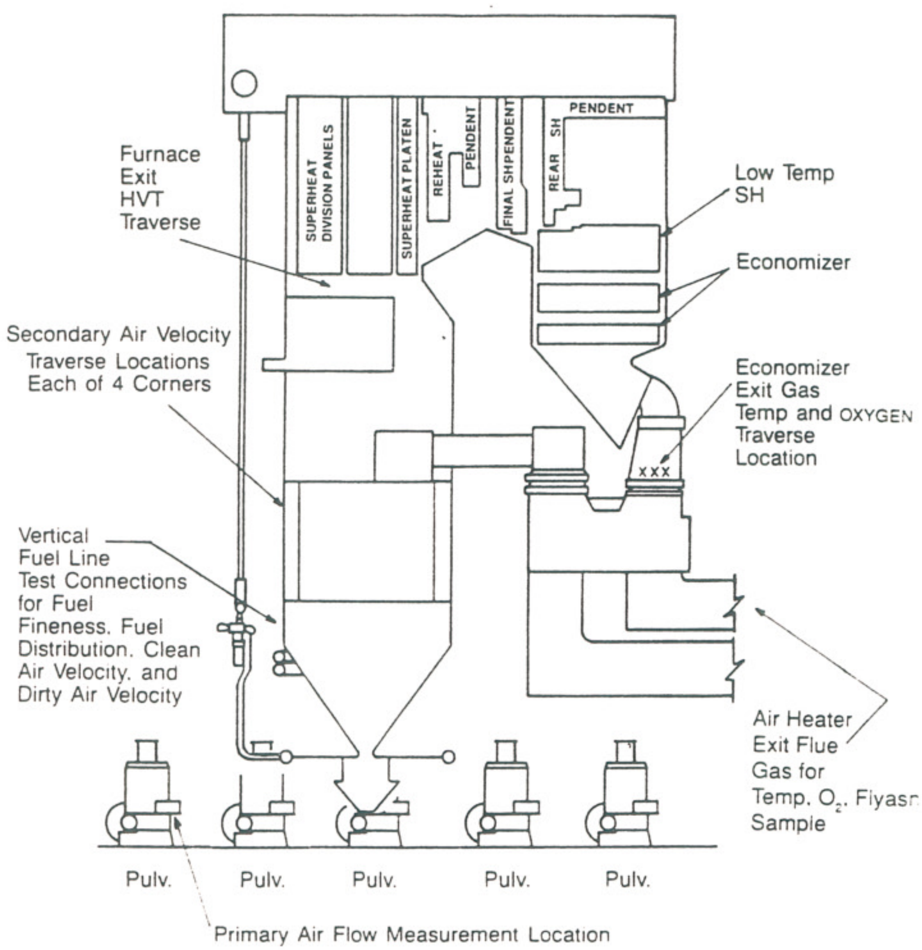
The results of the ten changes from the late 60's to 1987 indicated that there were other variables that were limiting the effectiveness of well thought out engineering solutions. Based on this previous experience, it was concluded that the furnace exit gas temperature was varying from other variables, and those variables were suspected to be combustion air and fuel balance.

The identification and quantification of the combustion variables was undertaken by a Comprehensive Test Program. The comprehensive testing, which was completed in the Spring of 1988, consisted of a test team of up to twenty persons. This test program followed an approach outlined in the ASME paper, "Coal Fired Boiler Performance Improvement Through Combustion Optimization", by Storm and Reilly, and presented at the ASME JPGC in 1987.[1]

The preceding changes that were implemented from initial operation through 1985 were all pressure part changes to alter the heat absorption rates of the waterwalls, superheater, reheater and economizer.

The burner offset air nozzles which were installed in 1987 were intended to increase furnace absorption through reduced slag accumulation on the waterwalls. Testing in the Spring of 1988 indicated that the furnace exit gas temperatures were well in excess of the ash fusion temperature, and the desuperheating spray flows were still higher than desired. The testing locations are shown on the figure below.

CROSS-SECTION OF WCBS #6 STEAM GENERATOR



5 Raymond #823 Pulverizers

Comprehensive diagnostic testing was chosen for the advantage of determining critical cause and effect relationships in real time. For example, the furnace exit gas temperature at the nose arch was found to be in excess of 2,500°F at full load at many points. The ash fluid temperatures for many fuels that are fired from time to time were below 2,500°F. It was also found on this boiler that the furnace exit had a number of individual points that were in a reducing atmosphere, or zero excess oxygen. Nearly all fuels have ash fusion temperatures that are lower in a reducing atmosphere than in an oxidizing atmosphere. Since many of the opportunities for improvement that were experienced on this boiler were slagging related, this was a significant factor. Typical fusion temperatures of the ash are shown on Figure 18.

The furnace exit, excess oxygen and temperature stratifications had to be the result of a non-homogeneous mixing of the combustion air and fuel in the burner belt zone. Zero oxygen points at the furnace exit could be due to either an abundance of fuel, or a shortage of combustion air. The Comprehensive Diagnostic Test technique was utilized to quantify the opportunities for each.

The data summary is shown on Figure 5 of pre-outage data which outlines opportunities for improvement.

PERTINENT PERFORMANCE DATA

Parameter	Pre-Outage	Comprehensive Pre-Outage Testing	Comprehensive Post-Outage Testing - Optimized Jan. '89
Economizer Exit Gas Temperature °F	—	729 to 748 Test #8 4-19-88	701-716°F
Final Reheat Split Side to Side °F East to West	—	20-41°F	0-5°F
Secondary Air Distribution to Corners		± 30%	± 11-14%F
Air Heater Exit Gas Temperature °F	287.3 to 305	303-304°F @ 5% O_2 Test #8 4-19-88	305
Full Load Reheat Spray Flow #'s/HR.	40,000	0 to 45,000	0 to 20,000
Full Load - Superheat Spray Flow #'s/HR.	180,000	210,000	145,000
Coal Fineness	—	62% Passing 200 Mesh	70-80% Passing 200 Mesh
Maximum Pulverizer Capacity with 70% Min. Passing 200 Mesh	—	Approx. 75,000 #/HR. @ 50 HGI	Approx. 95,000 #/HR. @ 50 HGI
Pulverizer Spillage #/HR.	—	Up to 500 #/HR.	Approx. 50 #/HR.
Furnace Exit Gas Temperature by HVT Probe °F	—	2325 Avg. Peak Temps. Above 2472°F Test #7 4-18-88	2,306F Avg. Peaks not Above 2325°F Test #3 - Jan. '89

FIGURE 5

The comprehensive testing identified opportunities for improvement, which became goals for the optimized fuel and air control. These goals were:

- **BEFORE ATTEMPTING ANY SORT OF SURFACE ADJUSTMENT, INSURE THAT OPTIMUM BOILER PERFORMANCE LEVELS ARE ACHIEVED (OCTOBER '88 OUTAGE MODIFICATIONS).**
- **FURNACE EXIT GAS TEMPERATURES BELOW SLAG FUSION TEMPERATURES AND REPEATABLE.**
- **DESUPERHEATING SPRAY WATER FLOWS REDUCED, S.H. TO APPROXIMATELY 5% OF FEEDWATER FLOW, REHEAT ZERO.**
- **CORRECT PROPENSITY FOR LOWER FURNACE SLAG ACCUMULATIONS.**
- **ACHIEVE DESIGN BOILER AND AIR HEATER EXIT GAS TEMPERATURES.**

Once the opportunities for improvement were identified, the modifications were designed for implementation during the scheduled Fall 1988 outage. The project schedule is shown on Figure 7, as the testing and modifications were actually completed.

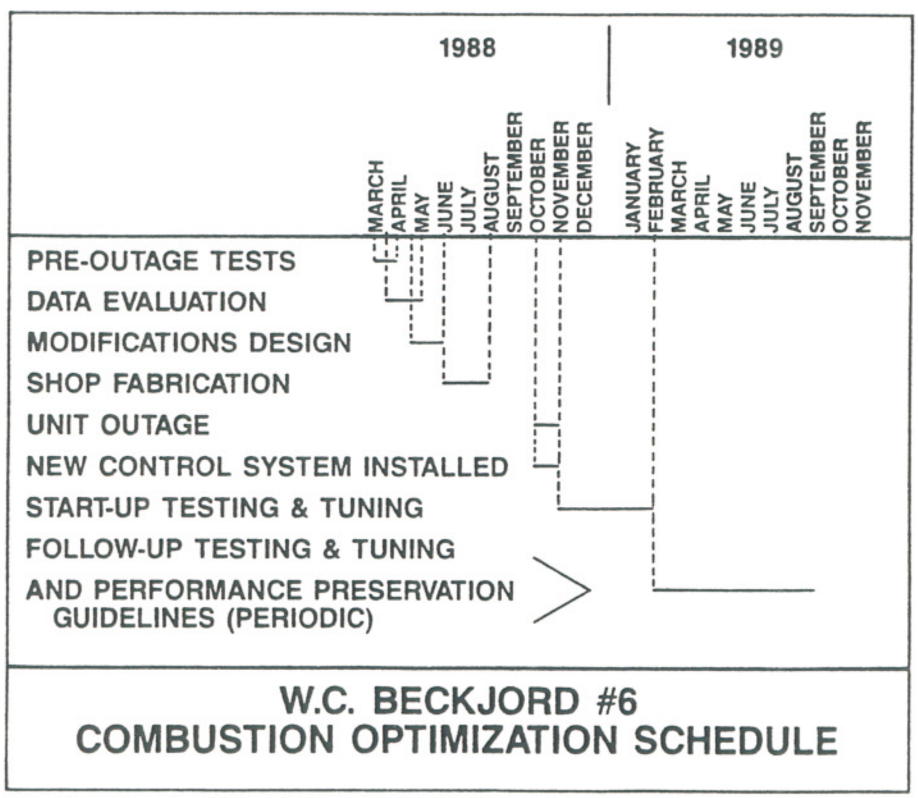


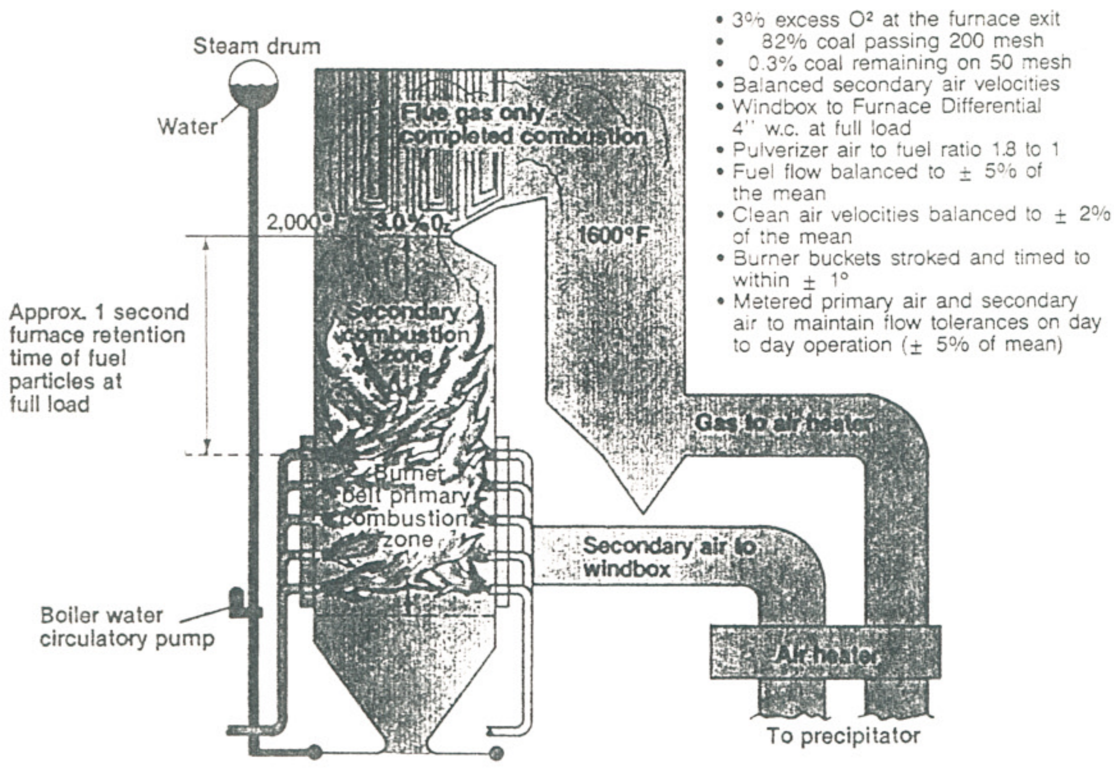
FIGURE 7

3.0 DESCRIPTION OF MODIFICATIONS

The comprehensive testing confirmed that significant improvements could be achieved in boiler and steam cycle performance. Further, it was concluded that additional surface changes would not be considered until boiler combustion performance was optimized.

Ten prerequisites for optimum combustion were identified, and the modifications were designed to address each of these. Figure 8 outlines the prerequisites for optimum combustion.

OPTIMUM COMBUSTION PRE-REQUISITES



TANGENTIAL FIRED UNIT
2400 PSI CYCLE

COMBUSTION OPTIMIZATION GUIDELINES - SUMMARY

- SECONDARY AIR BALANCING
- BURNER TILT TIMING
- FUEL BALANCING
- REDUCE AIR-IN-LEAKAGE
- CONTROL PRIMARY AIRFLOW

Figure 8

3.1 Secondary Air Balancing

Secondary air balancing to each corner was improved by windbox and secondary air duct partitioning, as depicted on Figure 9.

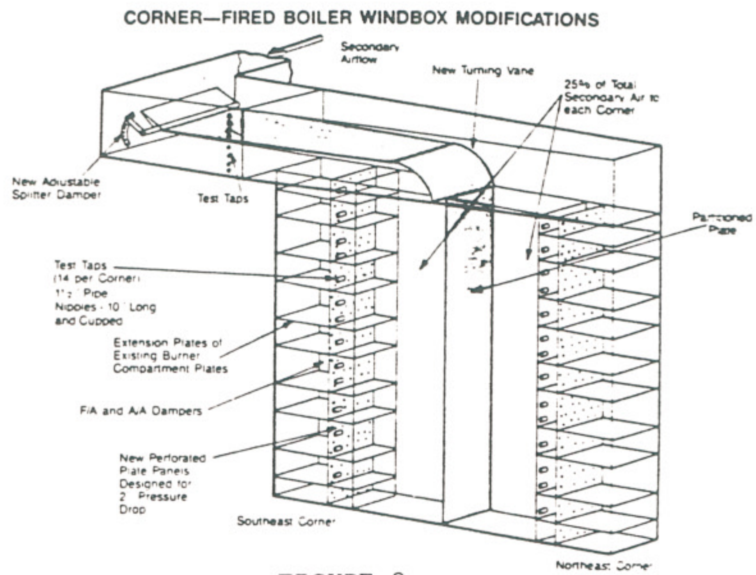


FIGURE 9

The improved combustion air balance has resulted in being the single largest improvement to reduce slagging in the upper and lower furnace zones. The unit load factor since the changes in 1988 has been increased, with significantly less load reductions for deslagging. The partitioning, perforated plate and division plates have resulted in a retrofit that could be implemented, tuned for optimization, and then easily maintained. The auxiliary air and fuel air dampers are intended for full opening at high load factor. The optimum position "full open" dampers at high load factor are easily duplicated to meet the goal of repeatable furnace exit gas temperatures. During the initial operation, slag at the lower furnace became objectionable. The lower perforated plate sections from each of the four corners was removed to increase the combustion air flow at the lower burner belt zone. This reduced slag formation in this area, and confirmed the boilers sensitivity to furnace slagging in areas of depleted oxygen.

3.2 Pulverizer Primary Air Flow Measurement

Primary air flow measurement and control proved to be important for optimum fuel fineness, flame symmetry in the furnace and for optimum air heater exit gas temperatures.

3.2 Pulverizer Primary Air Flow Measurement - Cont'd.

Subsequent testing has demonstrated that the air heater exit gas temperature is increased in the range of 25 to 30°F by non-optimized (high) tempering air flow.

The primary air flow measurement by round cross-sectional area flow nozzles has provided the capability to measure and control primary air flow to improve accuracy. Precise control of primary air flow to follow a prescribed primary air flow "ramp" requires a third volume control damper, the installation of which is planned for a future outage.

FLOW NOZZLE INSTALLATION

CINCINNATI GAS + ELECTRIC BECKJORD BOILER 6

FLAME REFRACTORIES TECHNICAL SERVICES

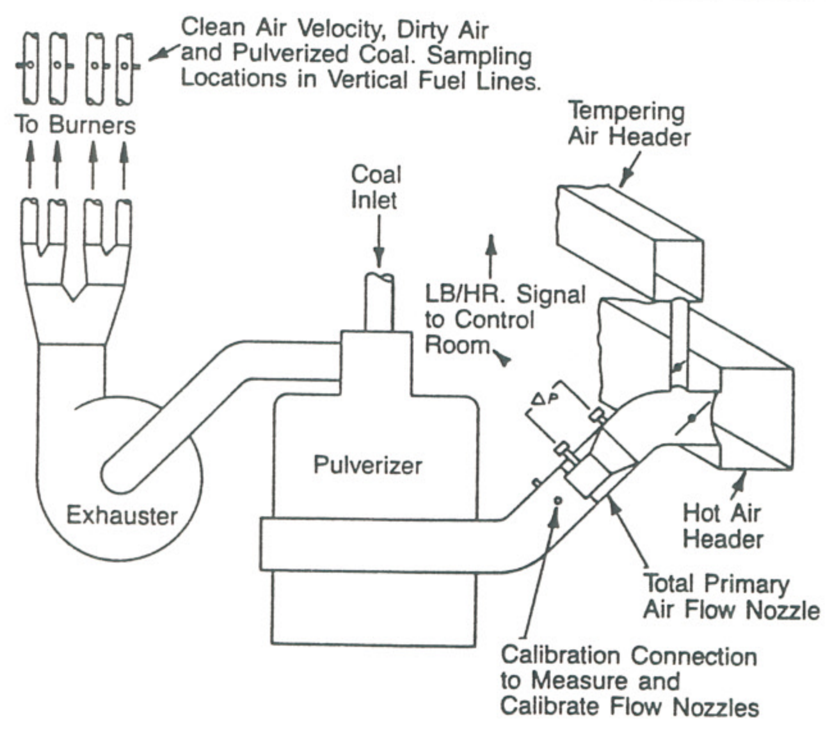


FIGURE 10

3.3 Fuel Line Balancing

Fuel line balancing was completed by clean air traversing of the fuel lines with pitot tubes, and then changing the orifices as required to achieve ± 2% or better balance on a "clean air" basis of each of the four pipes, from each pulverizer.

Fuel balance from the riffle distributers has been satisfactory, providing that the fuel fineness is above 72% passing a 200 mesh screen. Therefore, for fuel balancing, the changes to the pulverizer were to:

- Balance fuel lines on clean air (orifice changes)
- Restore critical roll to ring clearances
- Reduce rotating throat free flow area
- Extend outlet skirt of classifier
- Increase roll pressure for lower HGI fuels

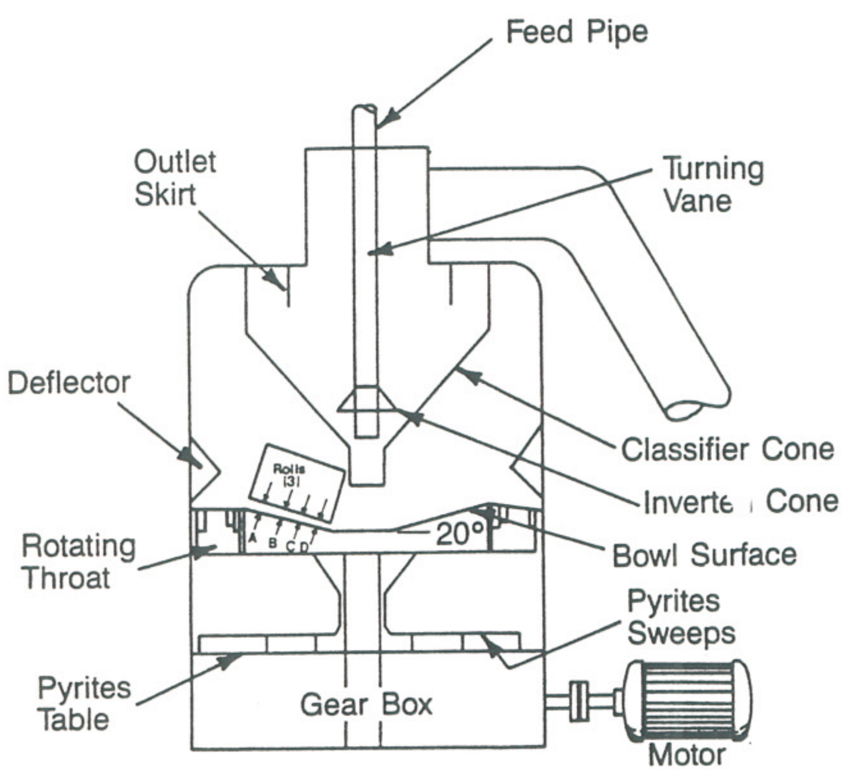


FIGURE 11

3.4 Outage Inspections and Repairs

During the Fall 1988 outage comprehensive repairs were completed for improvements in the following areas:

- Burner tilt timing and adjustable coal tip repairs as required.
- Precision stroking of dampers.
- Expansion joint repairs to reduce air in-leakage.
- Fan and pulverizer clearance checks.
- Coal feeder repairs and calibrations (Beckjord #6 has Gravimetric belt type feeders).

The furnace was scaffolded, and a very comprehensive boiler overhaul was completed. Following the outage repairs, implementation of the modifications and several months of tuning, the unit performed better than it ever had.

As a result of the modifications that were implemented, it was determined that boiler performance improvements were made in the following areas:

- **REDUCTION OF SUPERHEAT SPRAY FLOWS**
- **REDUCTION OF REHEAT SPRAY FLOWS**
- **REDUCTION IN SLAGGING OF THE FURNACE**
- **REDUCTIONS OF AUXILIARY HORSEPOWER CONSUMPTION**
- **REDUCTIONS OF TEMPERING AIR USAGE**
- **REDUCTIONS OF COAL DRIBBLE FROM THE MILLS**
- **BALANCED AIR AND FUEL FLOWS**

FIGURE 12

Superheat Sprays	Avg.: 210,000#/HR.	Avg.: 145,000#/HR.
Reheat Sprays	0 to Approximately 45,000#/HR.	0#/HR. to 20,000#/HR. It should be noted that reheat sprays can be maintained at zero if optimum sootblowing is achieved.
Reheat Temp. Split (east to west)	20°F to 41°F	0° to 5°F
Economizer Gas Exit Temperature	725°F	716°F
Secondary Air Distribution to Corners	± 30%	± 11 to 14%
Average Coal Fineness	62% Passing 200 Mesh	70 to 72% passing. This is with test data of higher coal flows than pre-outage.

FIGURE 13

4.0 SUMMARY

The unit capacity factor has been as high or higher than it ever was prior to the modifications that were completed in 1988. The reduced slagging, which is near totally attributed to improved air flow distribution, is the largest single factor providing the capability to operate at high load factors.

The combined effects of improved fuel and air balance has reduced superheater and reheater desuperheating spray flows. This is a significant contributor to optimum heat rate operation.

The flyash carbon content has tended to average about one per cent (1%), and rarely exceeds one and one-half per cent (1 1/2%). This contributes to optimum heat rate operation.

The heat rate and capacity factor graphs for the recent past are shown on Figures 14 and 15.

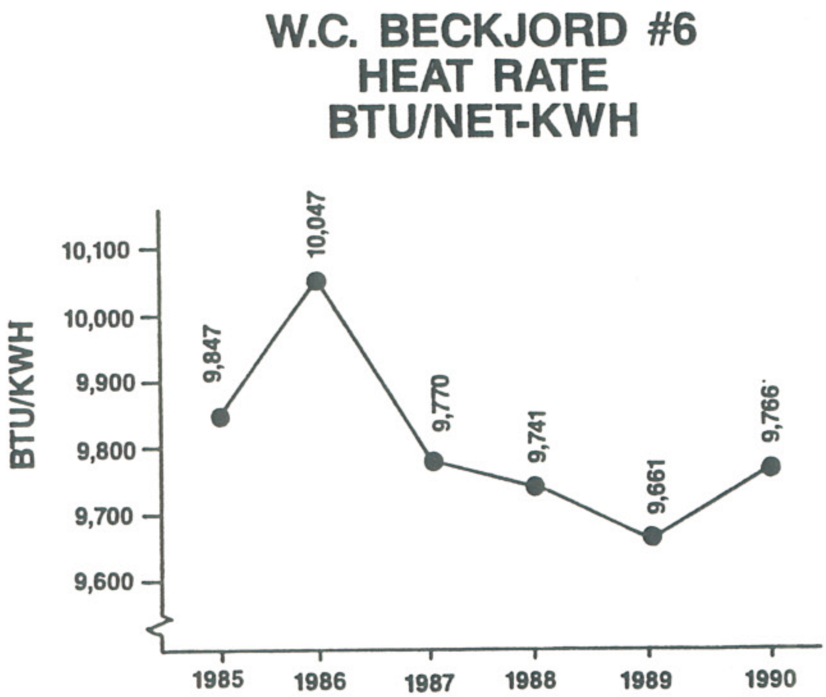


FIGURE 14

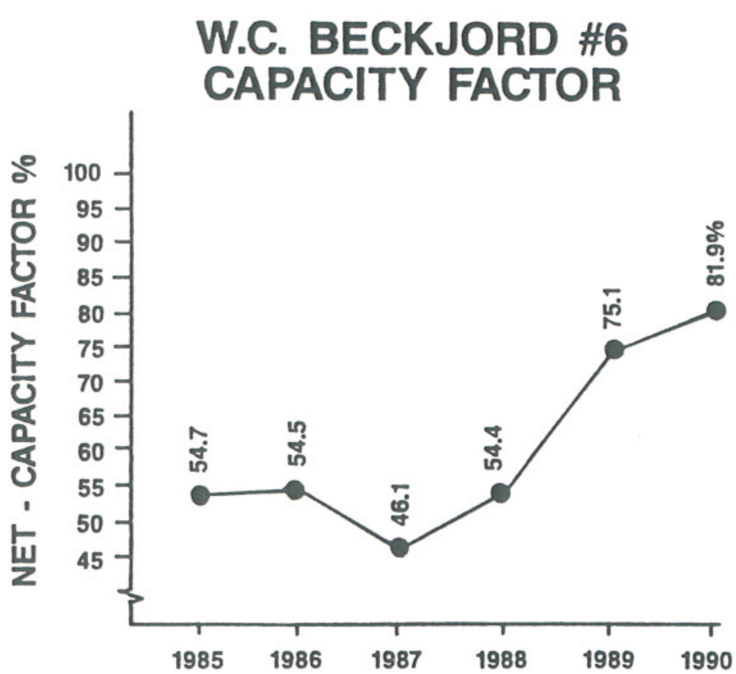
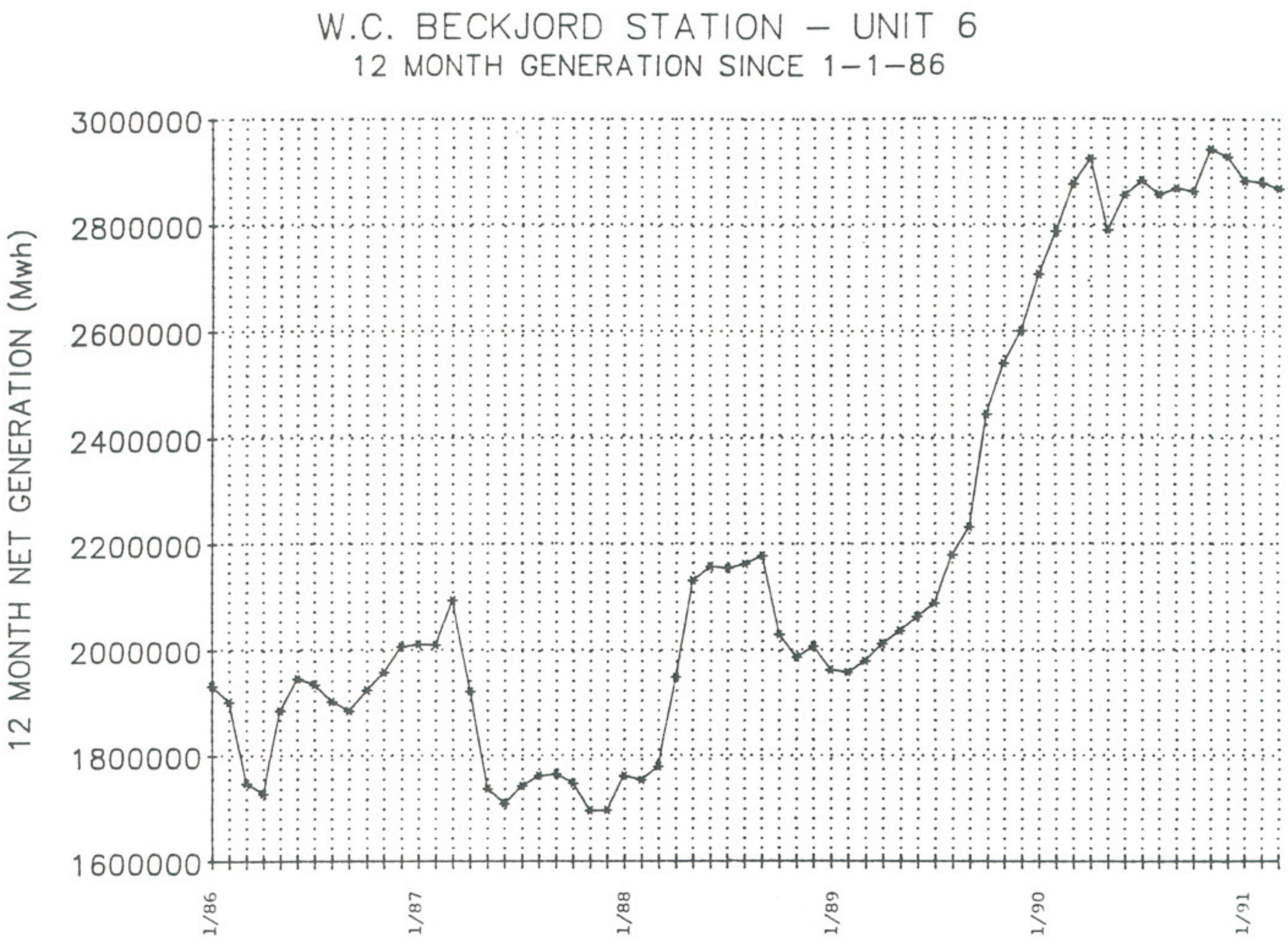


FIGURE 15

The twelve-month generation, in net megawatts, is shown on Figure 16.



4.0 SUMMARY - Cont'd.

Beckjord #6 fires Eastern Bituminous fuels, much of which is purchased on the spot market. Firing of fuel with low Hardgrove Grindability Index has caused periods of poor fuel fineness. The poor fuel fineness contributes to poor furnace heat release symmetry, which in turn contributes to slagging.

PROXIMATE ANALYSIS	As Received	Dry Basis
% Moisture	6.09	xxxxx
% Ash	15.63	16.64
% Volatile	31.71	33.77
% Fixed Carbon	46.57	49.59
	100.00	100.00
Btu/Lb.	11376	12114
MAF Btu		14532
Alk. as Sodium Oxide	0.25	0.27

GRINDABILITY INDEX = 45 at 1.50% Moisture

ULTIMATE ANALYSIS	As Received	Dry Basis
% Moisture	6.09	xxxxx
% Carbon	63.25	67.35
% Hydrogen	4.32	4.60
% Nitrogen	1.37	1.46
% Ash	15.63	16.64
% Oxygen (diff)	5.53	5.89

FIGURE 17

FUSION TEMPERATURE OF ASH, (°F)

	Reducing	Oxidizing
Initial Deformation (IT)	1955	2440
Softening (ST)	2180	2515
Hemispherical (HT)	2290	2585
Fluid (FT)	2400	2660

ANALYSIS OF ASH	WEIGHT %, IGNITED BASIS
Silicon dioxide	45.90
Aluminum oxide	20.50
Titanium dioxide	0.96
Iron oxide	26.94
Calcium oxide	1.36
Magnesium oxide	0.73
Potassium oxide	2.13
Sodium oxide	0.21
Sulfur trioxide	0.91
Phosphorus pentoxide	0.30
Strontium oxide	0.02
Barium oxide	0.00
Manganese oxide	0.04
Undetermined	0.00
	100.00

Silica Value = 61.26
Base:Acid Ratio = 0.47
T_{250} Temperature = 2340 °F

Fouling Index = 0.10
Slagging Index = 1.91

FIGURE 18

The high load factor operation, combined with much lower than pulverizer design HGI fuels creates an on-going challenge for the W. C. Beckjord Plant Maintenance, Operations and Engineering personnel, as CG&E has committed to increased duration between major overhauls. This requires that pulverizer maintenance be completed with the unit on-line, and with four or less mills in service. Of course, to keep a high load factor, this requires the four mills in service to operate at or above their design rated coal throughput. Therefore, it must be acknowledged that the success of the improved air and fuel controls is a complimentary component to day-to-day excellence on the part of the W. C. Beckjord plant personnel. The authors wish to acknowledge and thank all of the Beckjord people that have been involved in these accomplishments.

[1]ASME Paper 87-JPGC-Pwr-G