"Performance, Combustion, and Reliability Optimization of a 360 MW Unit Firing 90% Pulverized Coal and 10% Municipal Solid Waste"

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Introduction:

In order to increase the dispatch position of this 360MW Unit, it was necessary to implement various modifications/upgrades that would optimize performance, capacity factor, reliability and availability to meet the rising power demand in Central Florida. This Unit is co-owned by Orlando Utilities and City of Lakeland Electric and Water, who also is responsible for daily operations and maintenance. Each modification was individually evaluated and the cost justified for short term pay-back. The Unit went commercial in 1982 and was designed to operate firing 90% pulverized coal and 10% Municipal Solid Waste (MSW). Opportunities for improvement became evident shortly after start-up. Some of the improvements were necessary due to the design, while others required performance and combustion optimization. This paper will review the findings and explain the changes implemented over the last fourteen years. The opportunities for improvement were:

- Municipal Solid Waste firing was sporadic at best, with annual input being less than 1% of the total fuel fired
- Pulverizers experienced poor fineness results and large quantities of coal being discharged through the pyrite hoppers
- Superheat and reheat spray water flows were extremely high and exacerbated when firing Municipal Solid Waste
- Furnace exit gas temperature exceeded 2,400°F and fluid ash corrosion was experienced on high temperature superheater and reheater tubes and reheat tube failures resulted in less than 10 years
- High tube metal temperatures were found on primary superheater elements which were fabricated from carbon/moly material and premature tube failures resulted
- Convection pass tube thinning due to flyash erosion was evident at the location of the front and rear economizer up-legs
- Combustion performance and heat-rate were being penalized due to:
    - A) Increased primary air flow and poor control
    - B) Inconsistent secondary air flow measurement
    - C) Coal fineness below expected performance
    - D) High flyash loss on ignition (L.O.I.)
    - E) De-superheat spray flow quantities above design
    - F) Slagging
    - G) Condenser/cooling tower performance below design
    - H) Premature failure of metal seals at tube penetrations in the Penthouse creating large quantities of air infiltration through the damaged seals

Unit Description:

The City of Lakeland, McIntosh Station is located on the North side of Lake Parker in Lakeland, Florida. The Architect Engineering firm was Chas. T. Main, Inc. and steam generator was supplied by Babcock & Wilcox Company. The unit is a B&W Radiant Boiler which fires Eastern Bituminous Coal (a side elevation of the boiler and typical coal analysis is shown in Figure No. 1) and Municipal Solid Waste (MSW) in order to achieve 2,500,000 lbs/hr steam at 2400 psig throttle pressure and 360 Megawatts. The raw coal exits the Silos to the gravimetric belt type feeders which delivers the fuel to the four MPS-75 pulverizers. Each pulverizer supplies fuel and air to eight dual register burners (see Figure No. 2) for a total of 32. These are arranged in four rows with four burners in each row on the front and rear walls (see Figure No. 3). Municipal Solid Waste is delivered by truck, unloaded on the refuse building "Tipping Floor" and processed. Shredders, separators, and magnets are used to remove metals and non-combustibles. The material is then transported to an atlas bin where it is mechanically discharged into four pipes. The system uses blowers to supply 30,000 lbs/hr ambient air to each pipe to transport the refuse to MSW burners. The MSW burners are located at the same elevation as the upper most pulverized coal burners with two on each sidewall (see Figure No. 3). This unit may fire as much as 40,000 lbs/hr of refuse, However, normal use is between 20,000 - 25,000 lbs/hr. The steam is supplied to a General Electric turbine which is rated at 333 Megawatts.

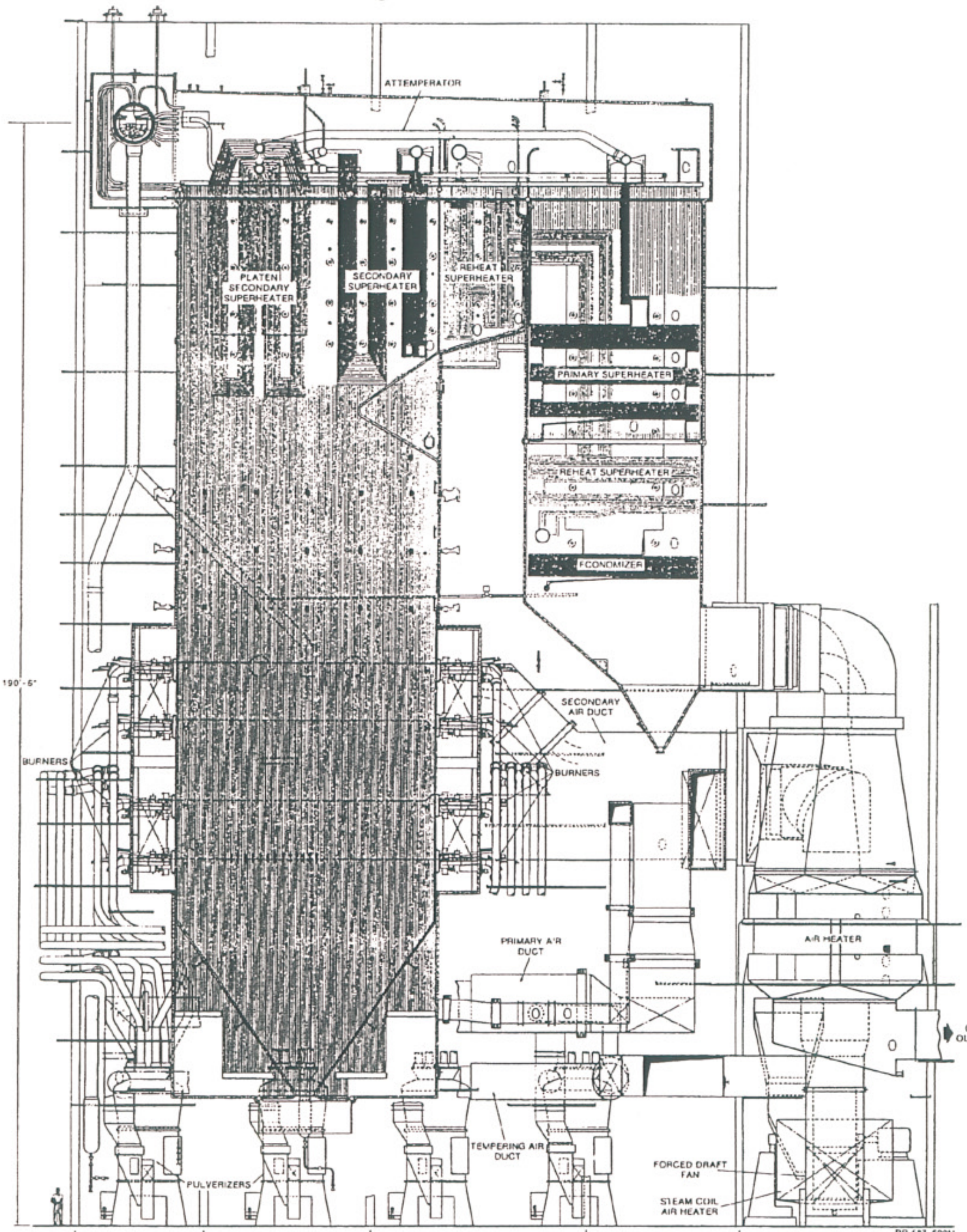


Figure No. 1 - Side-Elevation of Boiler

	As Received	Dry Basis
Moisture	5.50%	N/A
Ash	10.65%	11.27%
Sulfur	1.46%	1.54%
Carbon	71.25%	75.40%
Hydrogen	4.81%	5.09%
Nitrogen	1.52%	1.60%
Oxygen	4.81%	5.10%
BTU/lb	12,600	13,333

Hardgrove Grindability Index: 44

Mineral Analysis of Ash
% Ignited Basis

Silica dioxide	51.62%
Alumina oxide	28.12%
Ferric oxide	11.95%
Magnesia oxide	1.21%
Calcium oxide	1.04%
Potassium oxide	2.87%
Sodium oxide	0.57%
Titania dioxide	1.26%
Phosphorus pentoxide	0.49%
Sulfur trioxide	0.87%
Undetermined	0.00%

Ash Fusion Analysis

	Reducing		Oxidizing
Initial Deformation:	2601		2700+
Softening Temperature:	2669		2700+
Hemispherical Temperature:	2700+		2700+
Fluid Temperature:	2700+		2700+

Typical Coal and Ash Analysis of Fuel Supplied to this Unit

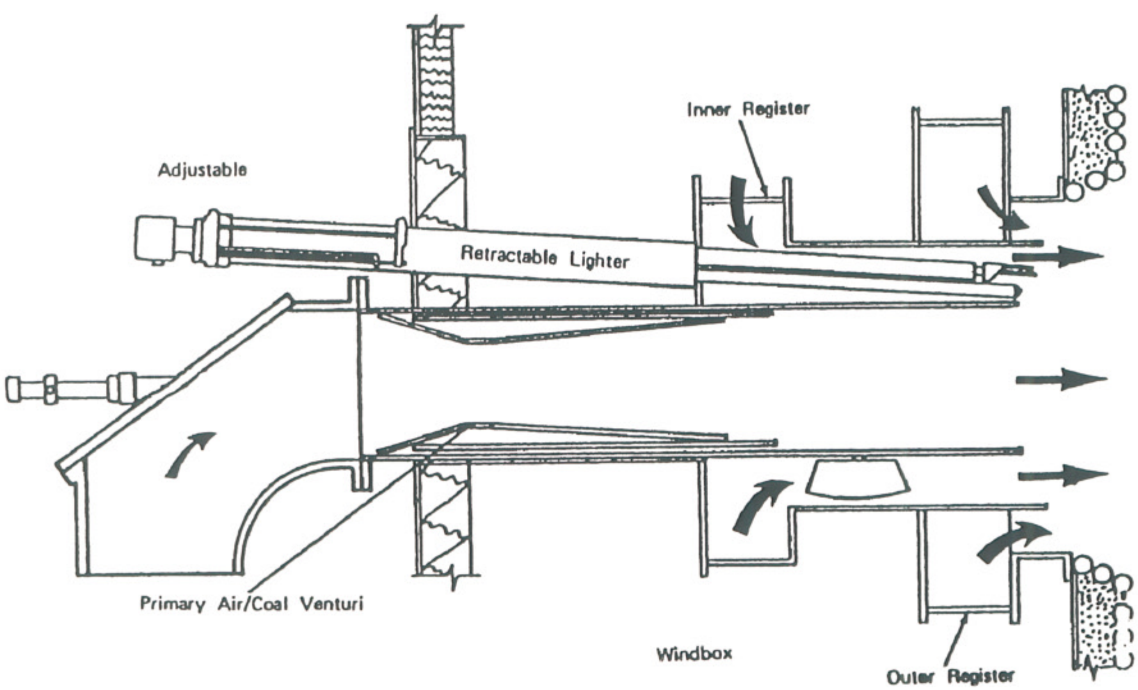


Figure No. 2 - Dual Register Burner

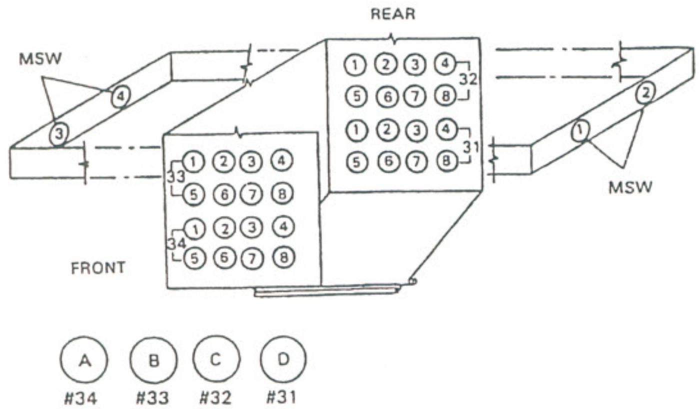


Figure No. 3 - Burner Arrangement

Opportunities for Improvement and Modifications Completed:

1. Secondary air and primary air management was unreliable since ash pluggage in the horizontal type air foils (Figure No. 4), averaging pitot tubes (Figure No. 5) and the sensing lines were common occurrences. Periodic field test proved that the flow calibrations of this equipment would constantly shift, making it difficult for the operators to balance and control the air flow rates. In both cases, the flow measuring devices were replaced using circular flow nozzles (see Figure No. 6) which have resulted in accurate (±3%) repeatable data over the last ten years.

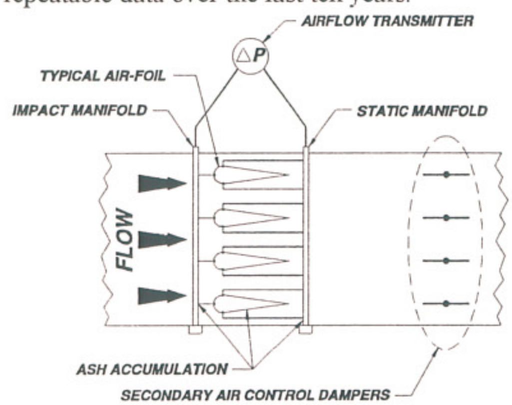


Figure No. 4 - Air-Foil For Secondary Air Measurement

(*was* typical for eight compartments)

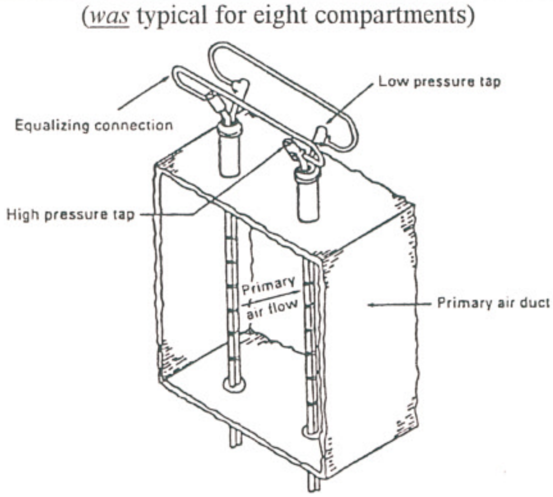


Figure No. 5 - Averaging Pitot Tube

(typical for all four primary air supply ducts)

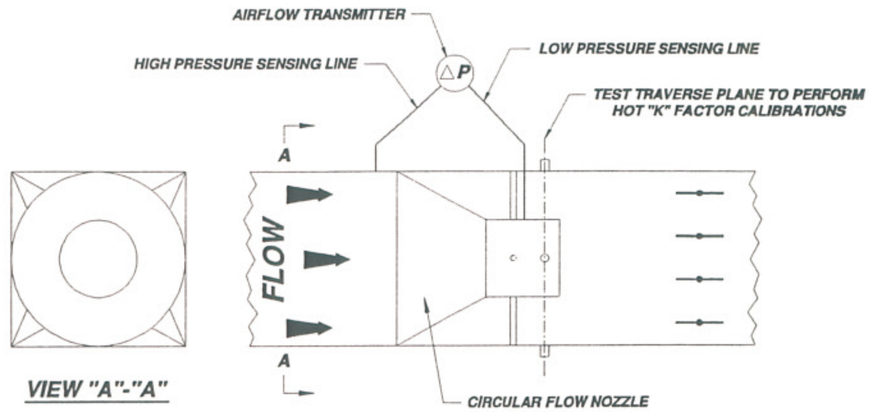


Figure No. 6 - Circular Flow Nozzle Arrangement

For Improved Primary and Secondary Air Flow Measurement, Accuracy and Repeatability

2. Primary air flow operated at air/fuel ratios of 2.5 pounds air per 1 pound of coal. The four MPS 75 pulverizers (see Figure No. 7) were designed for a 1.8/1.0 ratio. However, due to excessive coal dribble into the pyrite box, the air flows were increased. This caused a reduction in coal fineness, increased coal nozzle wear, and became a factor in unit performance and stack emissions.

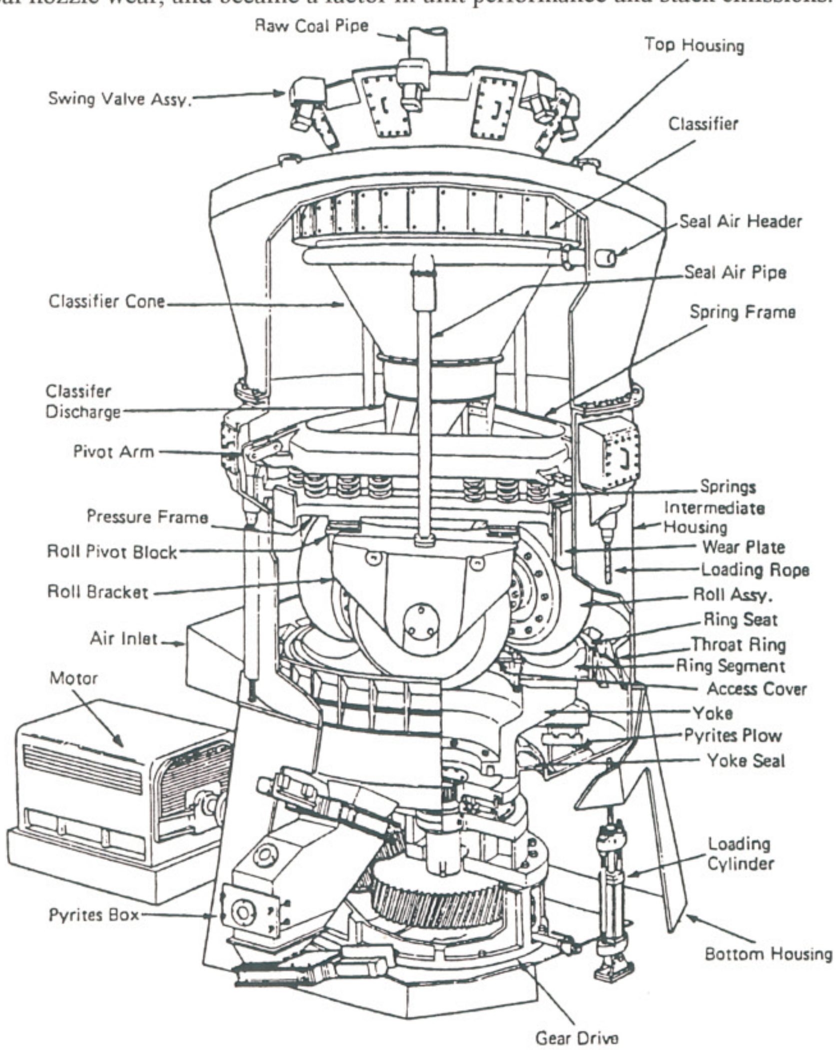


Figure No. 7 - Cut-Away of MPS Pulverizer

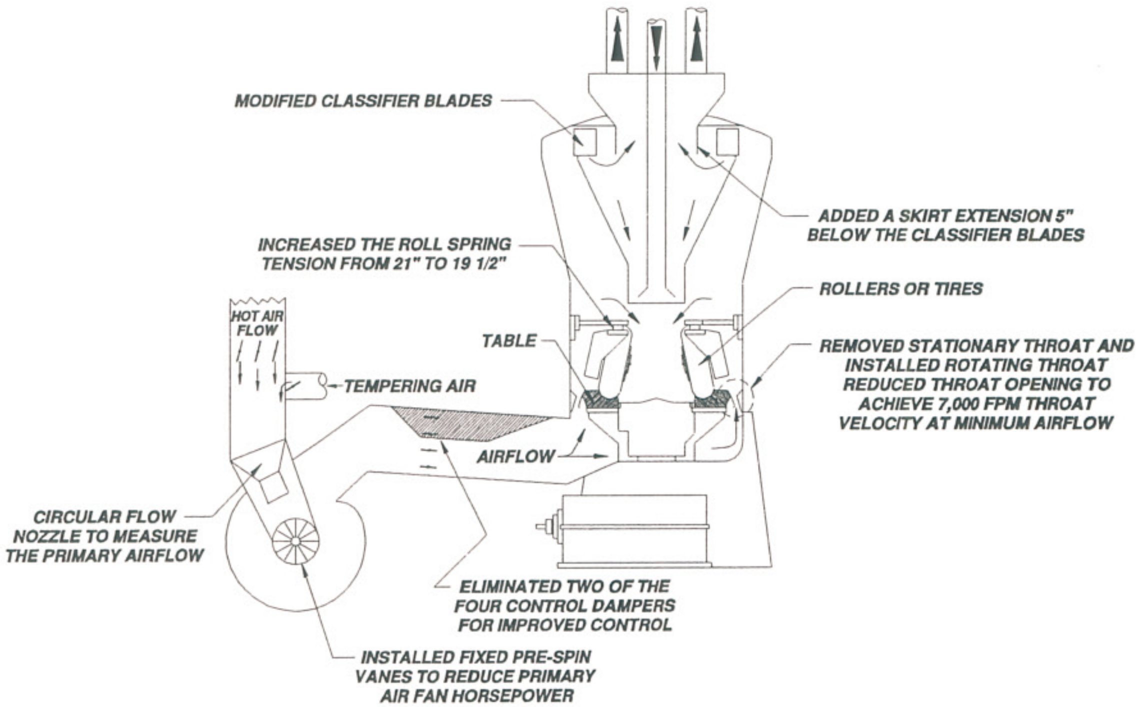


Figure No. 8 - Modification Applied to the Four MPS-75 Pulverizers

a. The 3½" stationary throat opening was modified to a 2½" opening (see Figure No. 9) for improved velocity and reduced coal dribble. The quantity of coal in the pyrite box was reduced from a few hundred pounds per hour to about five pounds per hour.

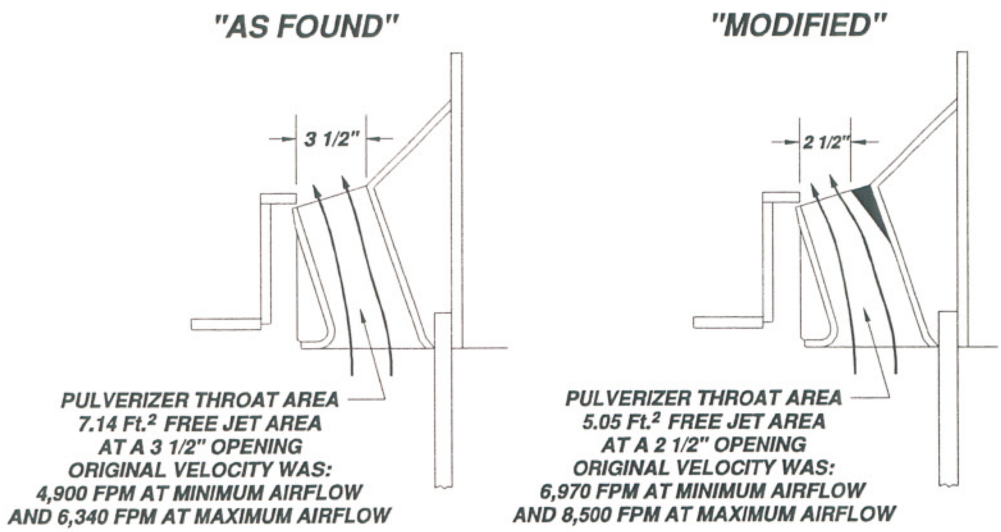


Figure No. 9 - "As-Found" and "Modified" Throat Openings

b. The classifier blades were modified from the original design straight blades (14" long) to a 26" long with a 10° angle (see Figure No. 10) for improved centrifugal rotation and fineness. The pulverizer fineness results were originally about 60% passing a 200 sieve and 1 to 2% on a 50 mesh sieve. The present fineness results of all four pulverizers are 75% passing 200 and less than 0.25% remaining on 50 mesh. All testing was using coal with an HGI of 40-45.

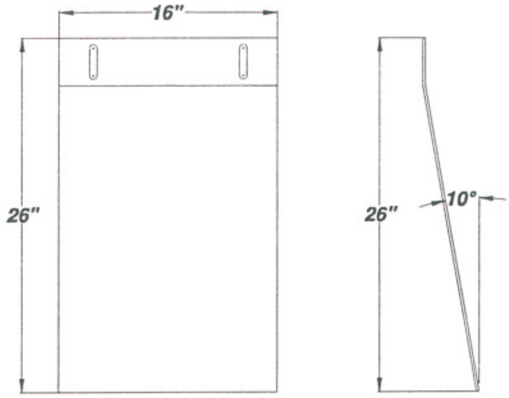


Figure No. 10 - Classifier Blade Modification

c. The skirt section was extended 5" below the classifier blades as shown earlier in Figure No. 8. This also was to improve coal fineness.

d. The control dampers were modified from a 4 louver to a 2 louver arrangement for improved control through the air flow ramp.

e. Fixed pre-spin vanes were installed at the P.A. fan inlet cone due to the oversized fans & excessive horsepower requirements (air horsepower was <400 while motor horsepower was 700).

f. Increased roll/tire spring tension from the original 21" setting to 19½" for better fineness results since the HGI of the coal is usually in the low 40's.

3. The coal nozzles were continually out of center since they were over 95" long and supported from the end of the windbox. This would lead to large ash formations around the burner tubes (eyebrows), and would also obstruct the spin vanes, preventing any possible adjustment. Naturally, this also causes poor flow geometry and air/fuel mixing in the burner zone. The coal nozzles were centered using four legs welded to the inner air sleeve and are set to maintain a ±1/4" tolerance (see Figure No. 11).

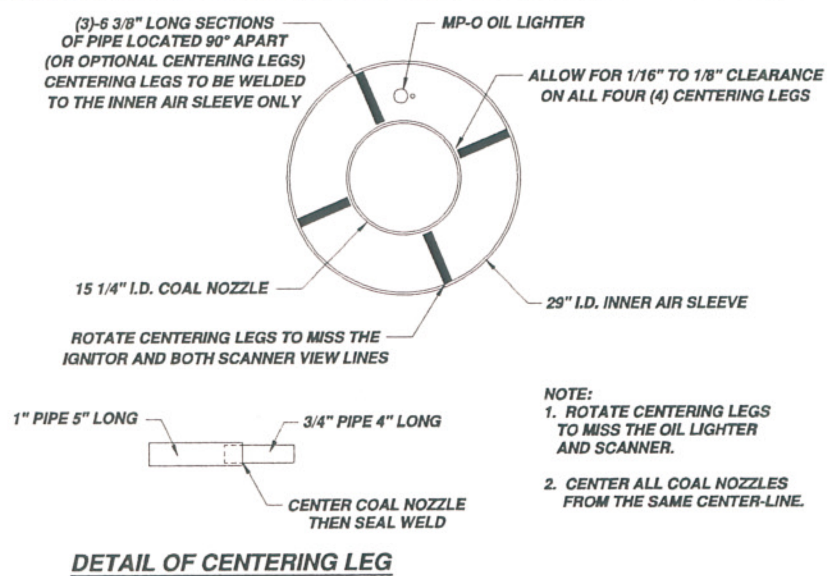


Figure No. 11 - Coal Nozzle Centering

4. The Municipal Solid Waste (MSW) and/or Refuse Derived Fuel (RDF) burners created various "opportunities for improvement".

a. Most of the refuse was actually being burned on the dump grates which are located at the furnace bottom ash hopper (see Figure No. 12), while the refuse entered the boiler through four MSW burners (see Figure No. 13) approximately 70' above the grates.

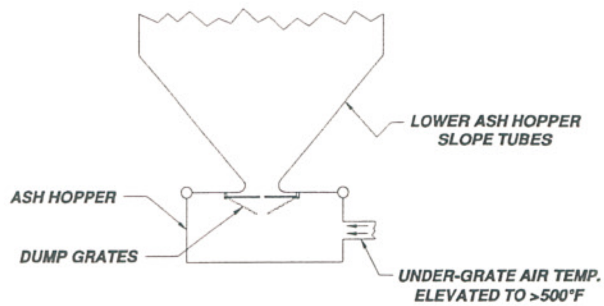


Figure No. 12 - Conceptual View of Dump Grates

b. The refuse transport air and burner combustion air would dramatically increase the gas mass flow creating excessive, de-superheat spray flows and tube metal temperatures. The MSW burners were modified from the nozzle axis being vertical (see Figure No. 13) to a larger nozzle and positioned with the long axis horizontal (see Figure No. 14). This was completed to create a lower discharge velocity and a wider spray pattern.

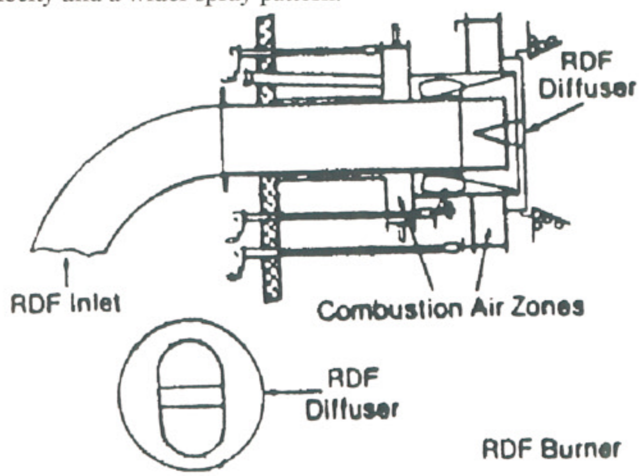


Figure No. 13 - Original MSW Burner

c. The MSW burners, as shown in Figure 13, was a dual register design which provides combustion air around the nozzle. This air was found to actually impact the flue gas mass flow only, and did not contribute to the combustion of the refuse. These registers were removed and refractory was installed to close off the opening, as shown in Figure No. 14. This assisted in the reduction of superheat spray water flow rates from over 12% of steam flow to about 9%.

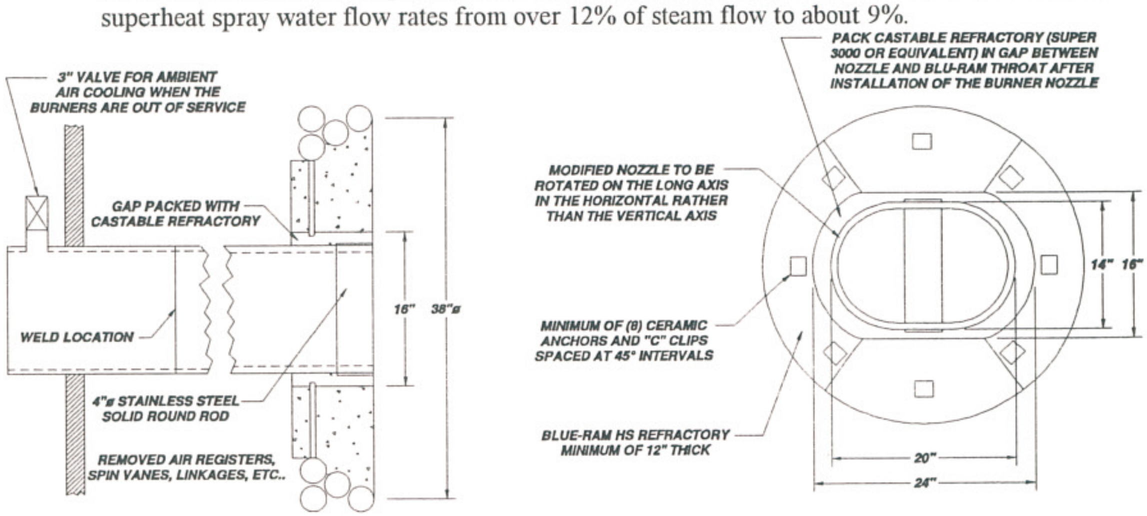


Figure No. 14 - Modified Refuse Burner

d. Various modifications were completed to the handling, processing and storage bin of the refuse for a continuous stable feed rate. New refuse fluffers and atlas bin sweeps were required to meet the demand and consistent feed. Maintenance in this area is still necessary as the entire system is usually off one day per week to conduct repairs, lubricate, and perform preventive maintenance. Refuse burning has increased from 20,000 tons/year in 1989 to almost 50,000 tons/year in 1996.

5. This Unit also experienced high quantities of air infiltration through the damaged metal seals in the Penthouse. This air would not contribute to the combustion of the fuel. However, it would be measured by the economizer exit gas oxygen analyzers. Due to this, the actual operation of the unit was well below the required excess oxygen necessary in the combustion zone for optimum performance. Since 1992, the Unit has had new seals (see Figure No. 15) and weld repairs performed during each outage to eliminate the air leakage.

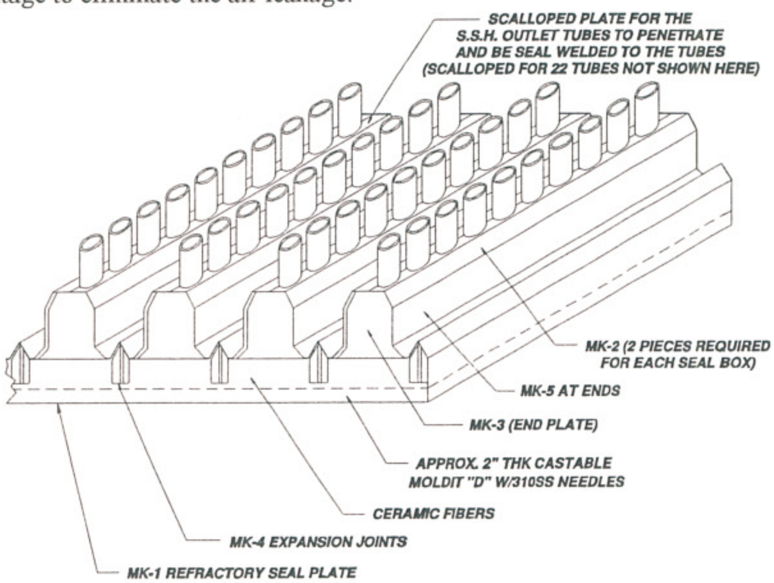
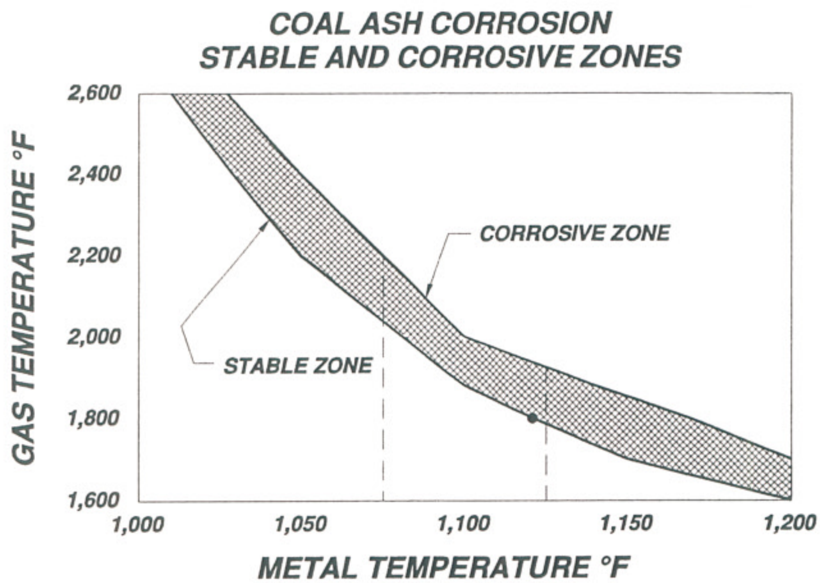


Figure No. 15 - Conceptual View of High Crown Seals

6. The previous opportunities/modifications, as well as various other changes completed on this Unit, were identified and completed using the following twelve essentials for optimum combustion.
   - Prove that the furnace exit is oxidizing with about 3% excess oxygen.
   - Fuel pipes balanced to each burner by "Clean Air" velocities ±2%.
   - Fuel pipes balanced to each burner by "Dirty Air" velocities ±5%.
   - Fuel pipes balanced to each burner Isokinetically, Air/Fuel ratio sampler ±10%.
   - Primary airflow to each pulverizer within ±5% of mean.
   - Pulverizer airflow measuring accuracy within the range of ±2 to 5% precision.
   - Fuel Fineness to all coal pipes >75% passing 200 mesh and <0.1% maximum on 50 mesh.
   - Pulverizer Air/Fuel Ratios 1.8.
   - Minimum Fuel Line Velocities 3,250 fpm.
   - Secondary airflow to each burner ±10% as best can be determined.
   - Mechanical tolerances of burners & dampers ±1/4". Dampers stroked within a tolerance of ±2°.
   - Constant & accurately fuel flow fed to each pulverizer with a smooth response to load changes.

Long Term Findings, Results, and Modifications:

1. In 1992, the reheater outlet bank (see Figure No. 16) experienced tube wastage due to fluid "coal ash corrosion". This was after only ten (10) years of operation. Some tube wall thickness' were below 0.100", while original minimum wall thickness was .203". The tubes had a 50% reduction in wall thickness due to gas temperatures measured by a water-cooled High Velocity Thermocouple (HVT) operating at 2,000°F to 2,200°F, while tube metal thermocouples were between 1,050°F and 1,125°F. The following graph shows that these tubes were mostly operating in the corrosive zone.



The flue gas and metal temperatures would increase when MSW burners were "in service". For this reason, as well as the metallurgical evaluation and ash analysis, we decided to upgrade the fifty-seven (57) assemblies from SA213T-22 (Chrome-Moly) to SA213TP304 (Stainless Steel). This was completed in 1993 and, to date, the tubes have little to no ash accumulation while the original tubes had to be mechanically cleaned during each annual outage. Combustion optimization has also improved the life of the new reheater tubes since the tube metal temperatures have been reduced to *no tubes above* 1,070°F and flue gas temperatures consistently remain below 2,000°F.

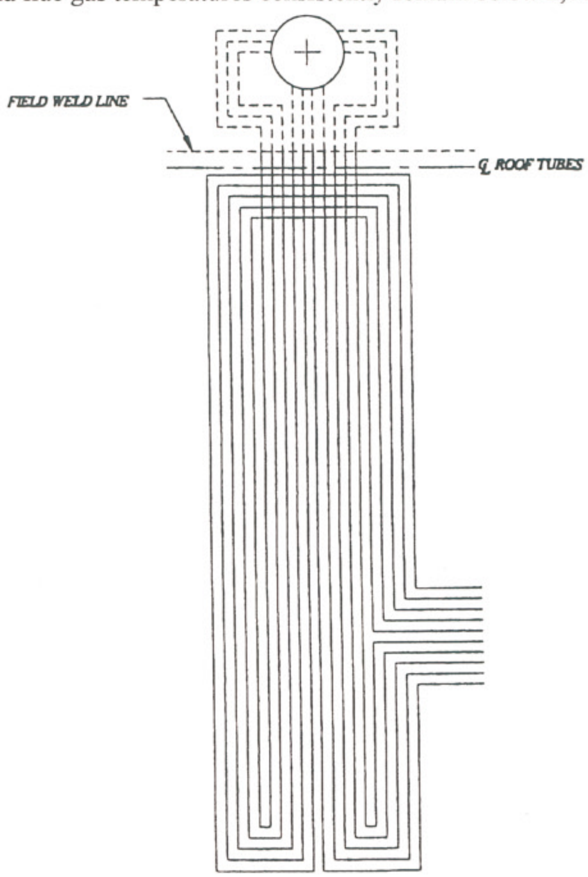


Figure No. 16 - Reheater Outlet Assembly Replaced in 1993(57 Required)

2. In 1993, the primary superheater tubes, upper bank experienced tube ruptures due to chain graphidization (see Figure No. 17). The metallurgical evaluation showed that these tubes have operated above 900°F for extended periods causing the long term failures. The following graph shows primary superheat tube metal temperatures for September 3, 1993.

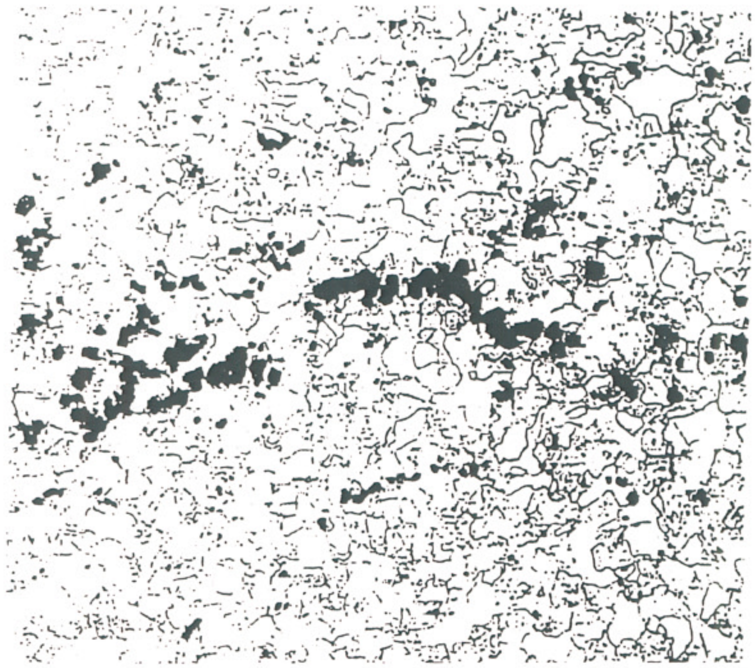
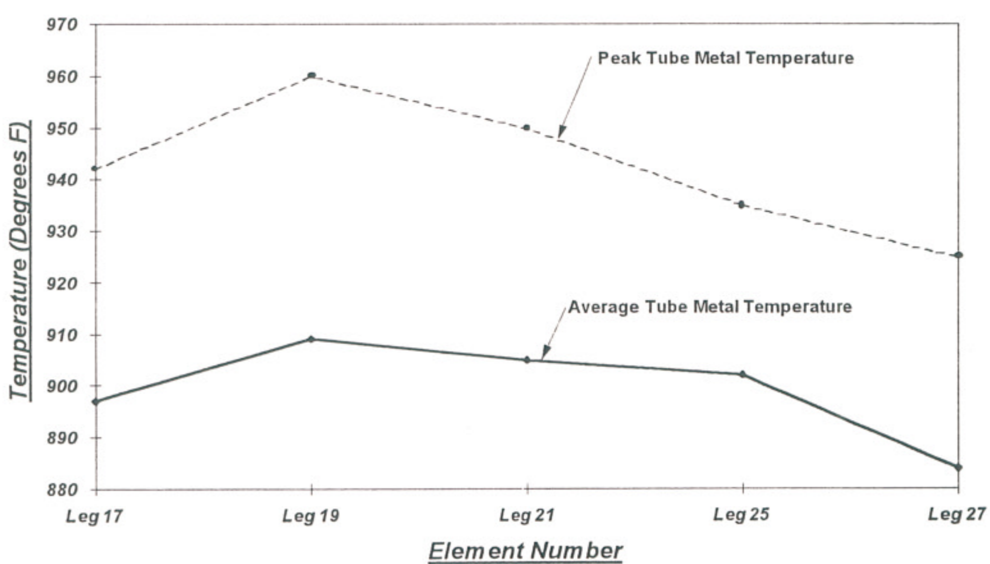


Figure No. 17 - Chain Graphidization in SA-209-T1A Tubes



Primary Superheater Tube Metal Temperatures

It is evident that these tubes, which are fabricated from SA209T1A (Carbon-Moly) material, were definitely operating above their allowable range. An evaluation was conducted using numerous tube samples from the upper, intermediate, and lower banks of the primary superheater (see Figure No. 18). Numerous tests were conducted of the flue gas temperature above and below each bank as well as recording of the PSH outlet tube metal thermocouples, PSH outlet steam temperatures, and spray water flow rates. Our resolution consisted of modifying, upgrading, and replacing the upper and intermediate banks of the primary superheater. Our changes were based on the following calculations:

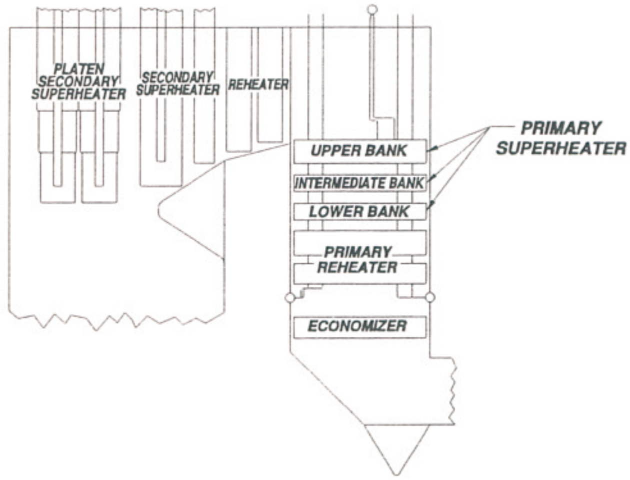


Figure No. 18 - Convection Pass Showing Primary Superheater

Calculating Hoop Stress:

$$\sigma = \frac{\text{Pressure} * (\text{Diameter - M. W. T.})}{2 * (\text{M. W. T.})}$$

Pressure = 2750 psi
Diameter = 2" O.D.
MWT = .203

Thus: $$\sigma = \frac{2750 * (2.000 - 0.203)}{2 * (0.203)} = 12{,}172\,psi$$

A remaining life assessment can be determined from the Larson Miller Parameter (LMP) at a stress value of 12,200 psi and different temperatures. A LMP value of 34,800 for SA-209-T1A can be found from Figure No. 19 and a LMP value of 35,200 for SA-213-T11 is found from Figure No. 20.

Carbon/Moly Tubes

SA-209T1A @900°F Tube Metal Temp.
≈ 48.5 yrs.

SA-209-T1A @ 925°F Tube Metal Temp.
≈ 17 years

SA-209-T1A @ 950°F Tube Metal Temp.
≈ 6 years

Chrome/Moly Tubes

SA213-T11 @900°F Tube Metal Temp.
≈ 95 yrs.

SA213-T11 @925°F Tube Metal Temp.
≈ 32.5 years

SA213-T11 @950°F Tube Metal Temp.
≈ 11.5 years

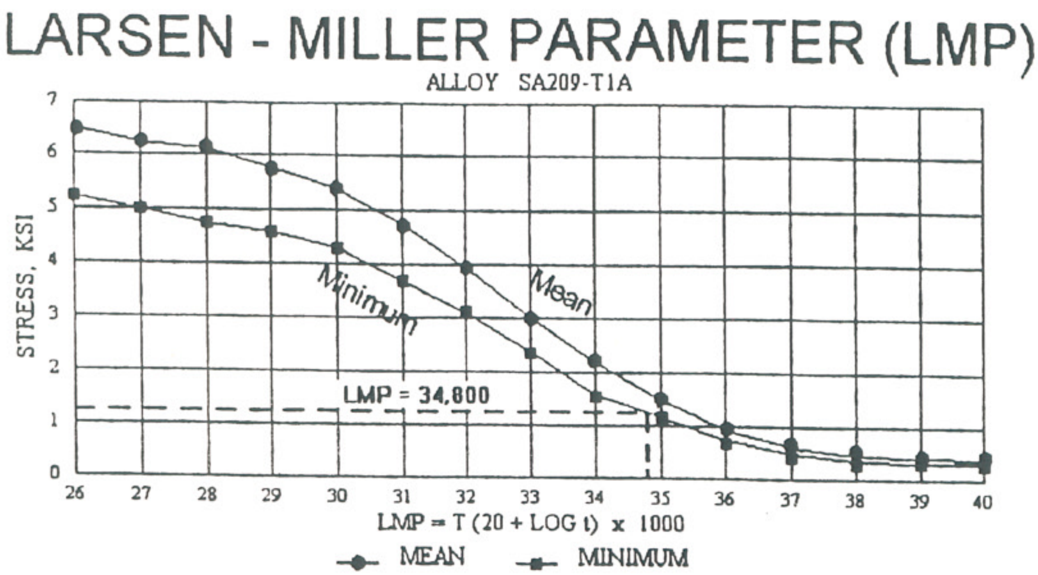


Figure No. 19 - Carbon/Moly - SA-209-T1A

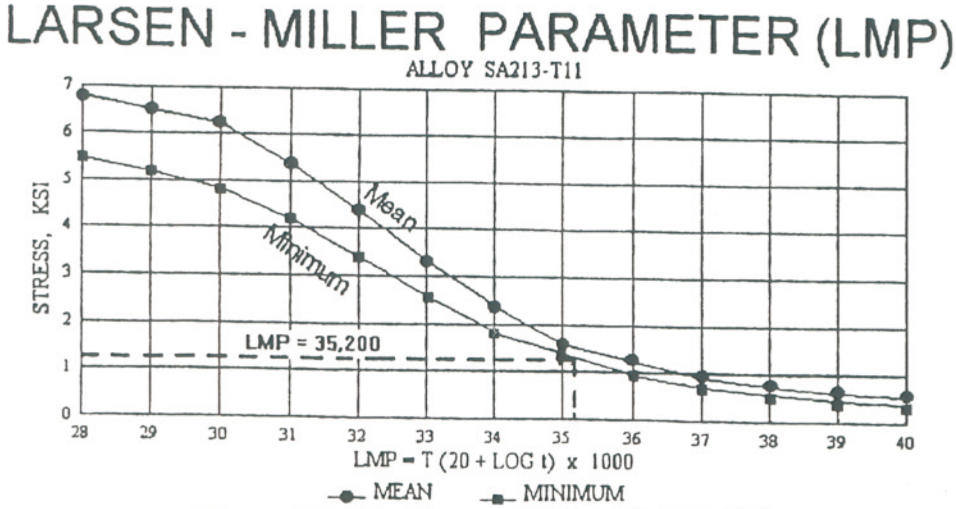


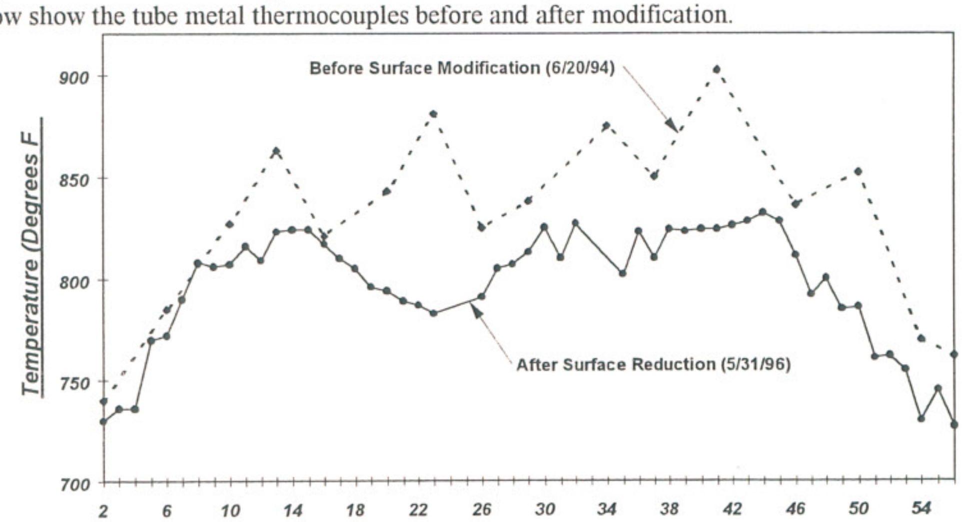
Figure No. 20 - Chrome/Moly - SA-213-T11

The following is the design change that was completed on the upper bank while the material on both the upper and intermediate was upgraded to SA213T-11.

	As Found at Full Load	Removed (4) Cross and Changed Diameter
P.S.H. Square Footage	123,109	111,917
Primary O.D.	2"	1 3/4"
No. of Crossings	22	18
P.S.H. Outlet Temp.	815°F	799°F
Superheater Spray	9%	7%
Total Superheater Pressure Drop	*189 psi	*194 psi
P.S.H. Pressure Drop	Base	5 psi
Velocity Entering P.S.H.	51.8 FPS	46.8 FPS
Gas Temp. Leaving P.S.H.	811°F	823°F
Gas Temp. Leaving L.T.R.H.	717°F	718°F
Gas Temp. Leaving Econ.	627°F	627°F
Change in R.H. Temp.	Base	4°F

* All Values Calculated Based on Test No. 4 and 7

The primary superheat modification has reduced spray water flow rates from 220,000 lbs/hr to 160,000 lbs/hr and the average tube metal thermocouples are 35°F lower at about 790°F. The graph below show the tube metal thermocouples before and after modification.



Primary Superheat Outlet Tube Metal Temperatures

Secondary Airflow
31 North Flow Nozzle

	"K" Factor	% Deviation
TEST No. 1	1,155,840	-0.17%
TEST No. 2	1,147,366	-0.91%
TEST No. 3	1,173,394	1.34%
TEST No. 4	1,154,850	-0.26%
Average:	1,157,863	

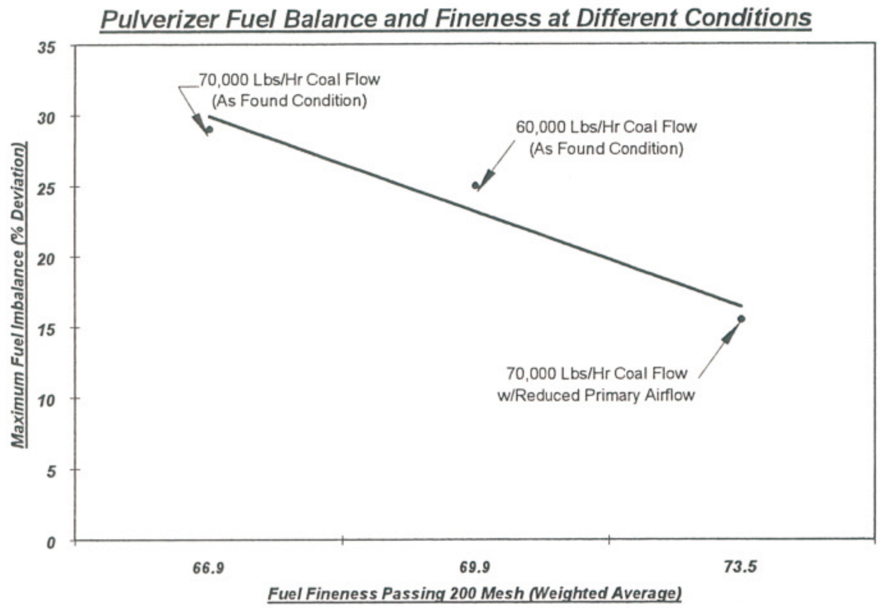
Secondary Airflow
31 South Flow Nozzle

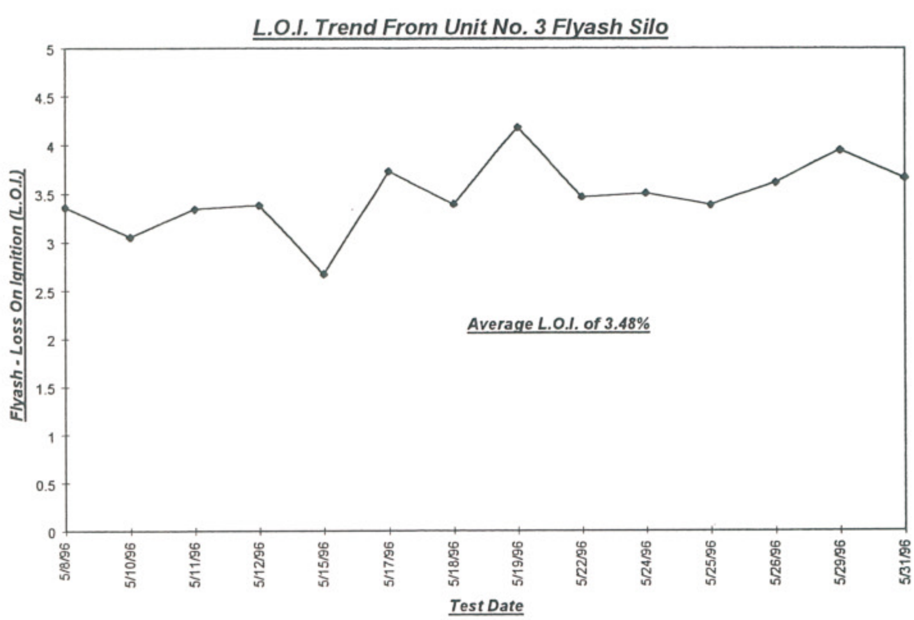
	"K" Factor	% Deviation
TEST No. 1	11,509	1.34%
TEST No. 2	11,441	0.74%
TEST No. 3	11,199	-1.39%
TEST No. 4	11,280	-0.68%
Average:	1,135,715	

Primary Airflow
31 Pulverizer Flow Nozzle

	"K" Factor	% Deviation
TEST No. 1	334,046	0.23%
TEST No. 2	334,175	0.27%
TEST No. 3	331,450	-0.55%
TEST No. 4	333,469	0.06%
Average:	333,285	

Secondary and Primary Airflow Calibration Results





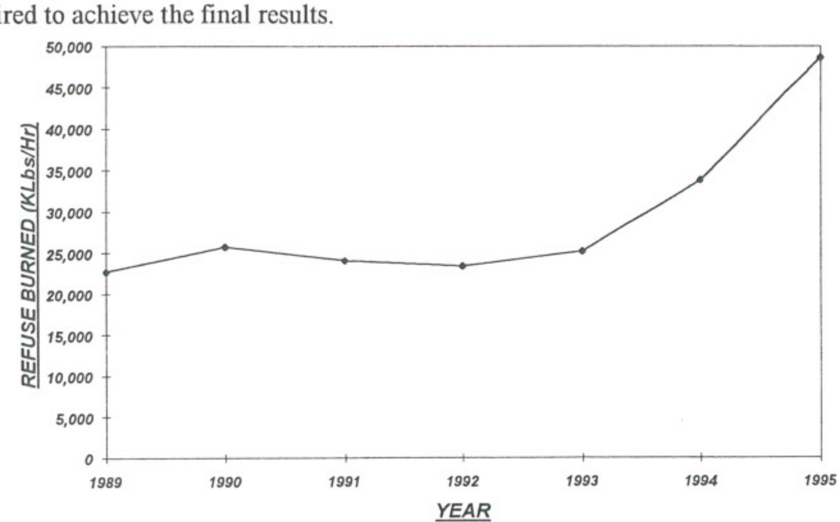
Future Projects:

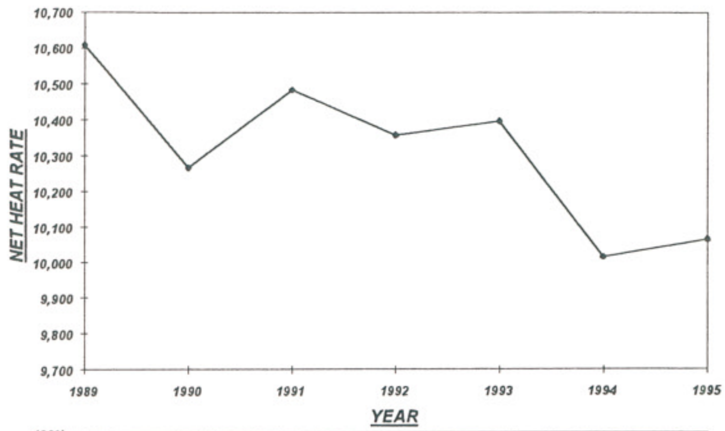
Review of a five year plan to continue with improvements in availability, heat rate, NOx emissions, and cost per kilowatt hour.

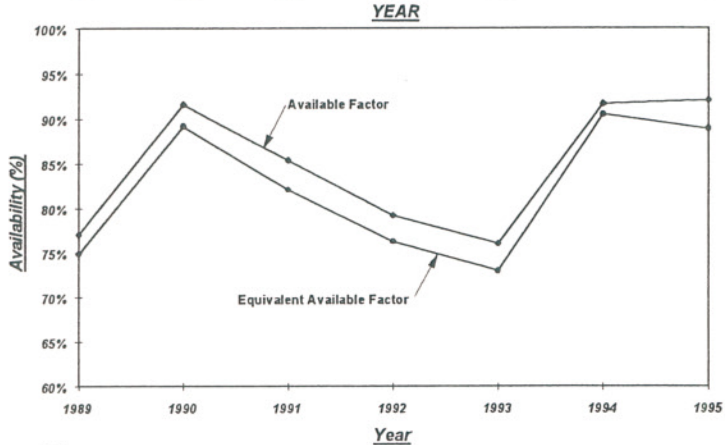
1. Upgrade existing burner air registers to allow proper movement of both the inner and outer register blades. Upgrade the material and linkage.
2. Reduce the NOx emissions below 0.45 Lbs/MMBTU with optimum register positions & burner airflow balance.
3. Develop reliable operation with an approximate fuel mix of 72% Pulverized Coal, 18% Petroleum Coke, and 10% Municipal Solid Waste.
4. Improve pulverizer fineness results using additional classifier modifications.
5. Replacement of high temperature superheater outlet tubes with a combination of Inconel, Stainless Steel, and Chrome/Moly to improve the corrosion characteristics of Coal, Petroleum Coke, and Municipal Solid Waste.

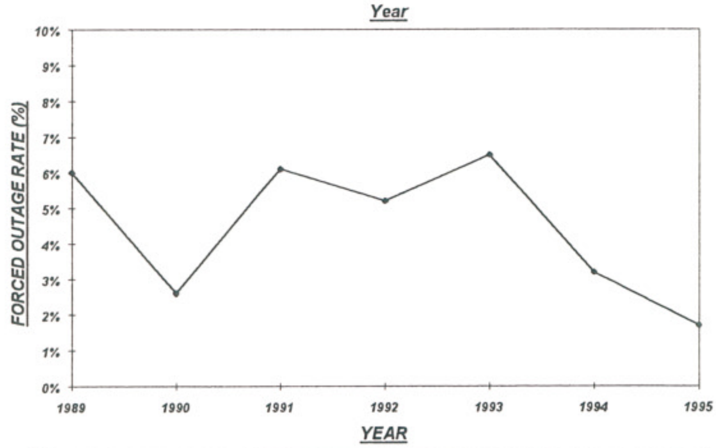
Summary/Conclusions:

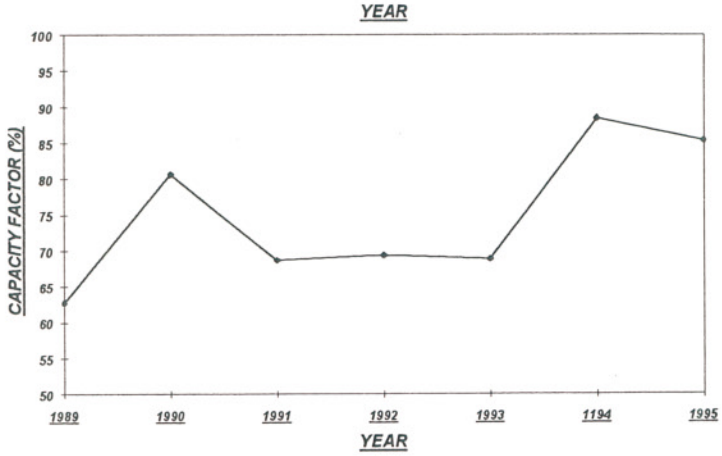
- The success required performance optimization, as well as numerous modifications to achieve the results that the City of Lakeland were committed to maintain. The long term relationship and team efforts put forth by the City and Storm Technologies provided a cost effective approach, and all modifications were financially justified.
- Developing and training operators while improving their awareness to the factors that increase reliability, capacity factor and boiler efficiency have already proven successful.
- Graphs of the following achievements are submitted on a yearly basis.
  - A. Refuse burning increased from 20,000 tons in 1989 to almost 50,000 tons in 1996.
  - B. Unit heat-rate from 10,600 Btu/kWh in 1989 to 10,015 in 1994 & 10,065 Btu/kWh in 1995.
  - C. Unit availability was 77.1% in 1989 and was 92.1% in 1995.
  - D. The forced outage rate has improved from 6% in 1989 to 1.7% in 1995.
  - E. The unit capacity factor was 62.7% in 1989 to 85.38% in 1995. This Unit is presently the No. 1 dispatched unit in a Central Florida Power pool.
  - F. Combustion optimization has reduced furnace exit gas temperatures from 2400°F, to an average of 2150°F.
  - G. Flyash carbon loss has been improved from 10% to below 3.0%.
  - H. De-superheat spray flows have been reduced from 12% of feedwater flow to 7%.
  - I. NOx emissions have consistently operated below .50 lb/million Btu.
  - J. The Twelve Essentials to Optimum Combustion, listed previously in this paper, were the original criteria used to determine the overall improvements, modifications, and repairs that were required to achieve the final results.




NET HEAT RATE
10,700
10,600
10,500
10,400
10,300
10,200
10,100
10,000
9,900
9,800
9,700
1989
1990
1991
1992
1993
1994
1995
YEAR


Availability (%)
100%
95%
90%
85%
80%
75%
70%
65%
60%
Available Factor
Equivalent Available Factor
1989
1990
1991
1992
1993
1994
1995
Year


FORCED OUTAGE RATE (%)
10%
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
1989
1990
1991
1992
1993
1994
1995
YEAR


CAPACITY FACTOR (%)
100
95
90
85
80
75
70
65
60
55
50
1989
1990
1991
1992
1993
1194
1995
YEAR