PERFORMANCE OPTIMIZATION OF A BOILER EQUIPPED WITH LOW NOx BURNERS

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INTRODUCTION:

Growing competition in the power industry has led to many changes in the way O&M organizations are approaching plant operations. Budgetary constraints, proforma performance expectations, reliability concerns, and environmental compliance issues are now the driving forces behind plant operations. As with most new facilities, the focus for the operator of the Mecklenburg Cogeneration Facility was on reliability improvement during the early post-commercial period. As the "randomness" was eliminated from the facility and reliable operation became the norm, attention was turned to cost savings through performance improvement. At this time the income of the plant had basically been maximized and any profitability improvement could only come from cost reductions. The owners and operator of this facility both recognized the value of boiler performance improvement and committed the resources necessary to make the optimization program successful.

There were obvious opportunities for boiler improvements following start-up and early commercial operation of the plant. Flyash and bottom ash that visually looked like it needed to be run through the boiler again were very obvious signs that combustion was less than ideal. Low NOx burners were new to the operator and while higher levels of carbon in the ash (or loss on ignition) were expected, it was unclear as to how much penalty these burners would cause. Therefore the visibly dark ash was not the "warning flag" it might have been with conventional burners. Reliability concerns were at the top of the priority list, therefore optimizing combustion received little attention during early commercial operation. However, once attention turned to performance improvement the following combustion related problems had been identified:

- Flyash loss on ignition (LOI) levels of 9 to 10 percent
- High desuperheating spray flows (70 to 80 Klbs/hr)
- Visibly high levels of carbon in the bottom ash
- Sporadic NOx values, but within the permit limit
- Poor flame quality resulting in unstable boiler operation

Because of these problems and the effect they were having on the operator's ability to meet the requirements of the air permit and maximize the profitability of the project, a boiler optimization program was undertaken with the following desired results:

- Flyash LOI's of 3 to 5 percent under all operating loads
- Desuperheat spray flows of 40 to 50Klbs/hr at full load
- "Clean" bottom ash
- Consistent NOx levels of .30 to .32 lbs/MMbtu
- Consistent flame quality and stable boiler operation
- Predictable pulverizer performance throughout the wear cycle
- Ability to routinely perform boiler tests and track results

FACILITY DESCRIPTION:

The Mecklenburg Cogeneration Facility is located on the south shore of the John H. Kerr Reservoir near Clarksville, Virginia. It is owned by the Mecklenburg Cogeneration Limited Partnership which consists of American National Power of Houston, Texas and Duke Energy Corp. of Charlotte, NC. The plant was engineered, constructed, and is currently operated by Duke/Fluor Daniel of Charlotte, NC. The 132 MW facility consists of two independently operated, identical units. Each unit utilizes a single Foster-Wheeler 600,000 lb/hr pulverized coal boiler. The coal is delivered to the boiler by three Williams Model DF-64 pressurized pulverizers each supplying two burners. The pulverizers employ variable speed drives on both the main drive and the spinner/separator. Stock model 8424 gravimetric feeders control the coal flow to the pulverizers. Primary air is provided to the pulverizers from a single primary air (PA) fan whose discharge is split into a heated and unheated header. This air is mixed at each pulverizer to control outlet temperature. Secondary air is provided to the boiler from one forced draft (FD) fan supplying a non-partitioned windbox, front and rear overfire air ports (4 each), and boundary air at the bottom of the boiler. Each unit is equipped with six Controlled Flow-Split Flame Low NOx burners by Foster-Wheeler. Operation of the plant is controlled by a Bailey INFI 90 DCS. Each unit is dispatchable from 18 to 66 MW by the host utility. Export steam is provided to a nearby steam host via General Electric single auto-extraction turbines. Additional design data associated with the boilers is as follows:

• Drum pressure	1755 psig
• Turbine inlet conditions	950°F at 1575 psig
• Economizer water inlet temperature	412°F
• Economizer gas outlet temperature	290°F
• Furnace exit gas temperature	1930°F
• FD fan air inlet temperature	70°F
• Boiler efficiency	88.42%
• NOx limit	0.33 lbs/MM Btu - (30 day rolling average)

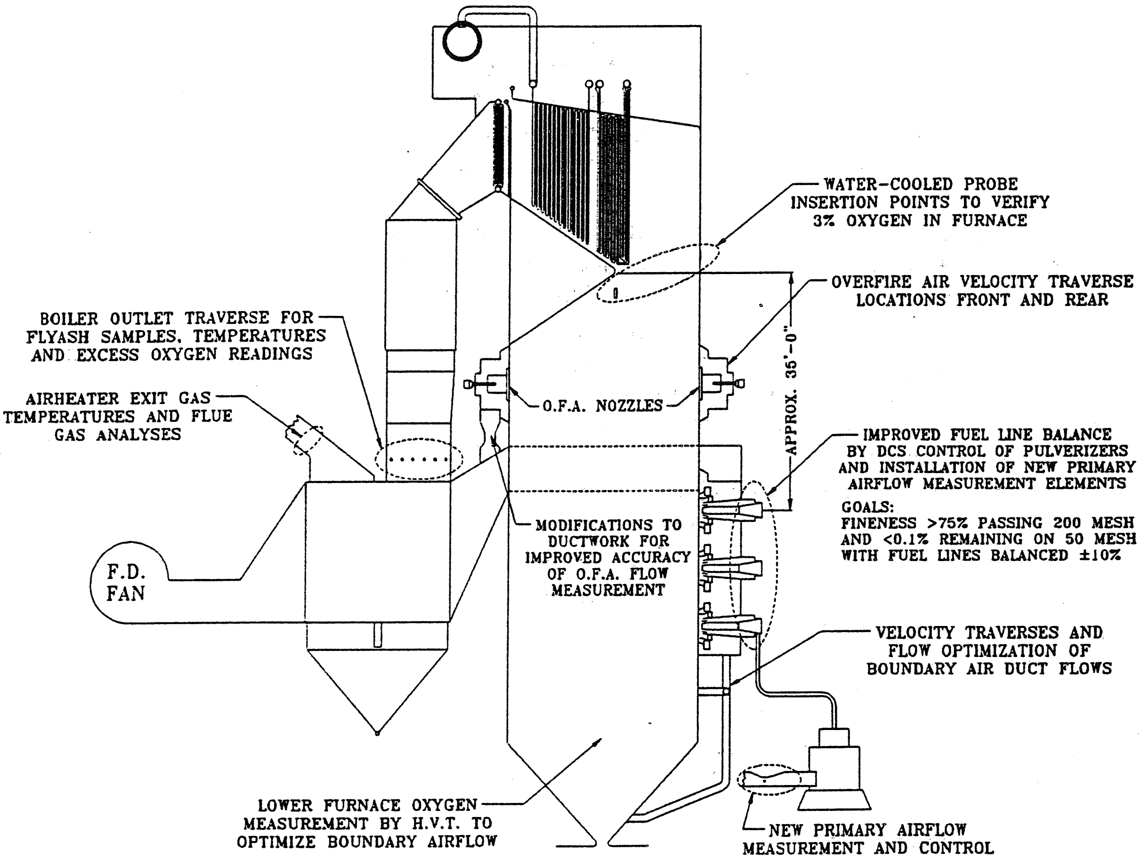


Figure No. 1 (Side Elevation of Boiler & Performance Optimization Factors)

INITIAL ASSESSMENT:

Once the desired results were defined it was determined that a combustion consultant would be necessary to help develop the program. The services of STORM TECHNOLOGIES, Inc. ("STORM") of Albemarle, NC were retained to initiate the optimization program. For the program to be successful a comprehensive approach had to be taken to the optimization process (See Figure No. 1). "STORM" personnel made an initial assessment of the boilers in June of 1994 and discovered high primary air flow and severe secondary combustion in the upper furnace. They quickly concluded that more air was needed in the burner zone. The low NOx burners are designed to operate at 90% stoichiometry which both limits maximum combustion temperature and eliminates free O_2 in the combustion zone, both of which contribute to reduced NOx production. However sufficient air must be introduced into the boiler to produce an oxidizing atmosphere at the furnace exit to ensure complete carbon burn out. Excessive secondary combustion in the upper furnace was noted by "STORM" which indicated insufficient carbon burn out in the burner zone. The secondary combustion was caused by re-ignition of the remaining unburned carbon as the over fire air (OFA) was introduced.

Some quick adjustments to the pulverizers and air registers as well as increasing the total air flow resulted in much better appearing flames, reduced secondary combustion, reduced superheat spray flows, and increased NOx while the hourly NOx levels were intermittently above 0.33 lbs/MMBtu during testing and optimization, the 30 day rolling average NOx, which is the air permit standard, was never compromised. The initial results were highly encouraging, however it became obvious due to increased NOx levels that a more in-depth approach would be required. "STORM" recommended a much more comprehensive analysis using sophisticated test equipment. "STORM" identified the following parameters as mandatory, to achieve optimum combustion:

- Oxidizing conditions at the furnace exit with approximately 3% excess O_2.
- Coal fineness of >75% passing 200 mesh and <0.1% remaining on 50 mesh.
- Fuel distribution within ±10% burner to burner.
- Primary air flow accurate and measurable.
- Primary airflow fit to a curve to insure proper air/fuel ratio (1.8-2.0 lb of air per lb. of fuel).
- Pulverizer line velocities above minimum velocity at low loads to prevent coal drop out and to position the ignition point at a distance from the burner tip to avoid coking and burner fires.
- Secondary air flow proportional to total fuel flow and controllable at burners, overfire air ports, and boundary air.
- Fuel flow to the pulverizers must be measured and controlled with smooth feed rates during load changes. A range of ± 1% actual to indicated fuel flow should be the tolerance on gravimetric feeders as verified by calibration.

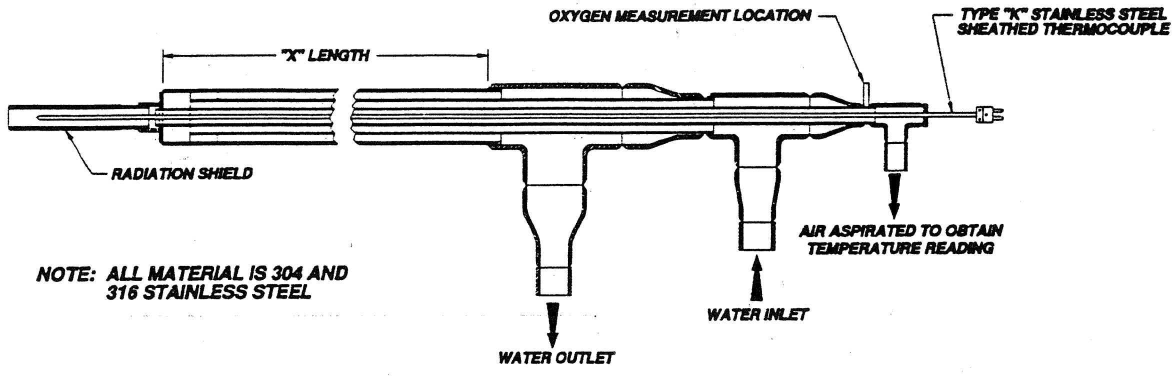
Ensuring these parameters were being met would require considerably more personnel and test equipment than were available during the initial assessment. "STORM" was scheduled to return in July, 1994 to begin the detailed optimization work.

TESTING AND OPTIMIZATION:

The initial test group consisted of both "STORM" personnel and plant operations personnel. The operator chose to use plant personnel for the testing, both for educational purposes and to develop the expertise in-house to perform routine testing once the optimization effort was completed.

Air Flow Management:

Ensuring sufficient free oxygen for combustion was the first step of the optimization effort. The challenging part of this step was to provide sufficient air to the burner area for complete combustion without creating excessive NOx. Originally the only available O_2 monitoring was located at the boiler outlet flue prior to the scrubber. Although this provided a reading of boiler exit O_2 concentration it gave little information about the oxygen profile across the boiler. Furnace exit gas traversing was performed immediately in front of the superheater using a water cooled High Velocity Thermocouple (HVT) probe (Figure No. 2) to obtain a detailed profile of the upper furnace O_2. This process was also helpful with side to side burner adjustments. Initial O_2 traverses showed 4% on one side of the furnace and 0% on the other. Maintaining 3% excess oxygen with no reading below 2% was achieved with some minor air register and total air flow curve adjustments.



HIGH VELOCITY THERMOCOUPLE (H.V.T.)

Figure No. 2

One of the original goals of the program was to maintain the level of NOx consistently below the permit limit of 0.33 lbs/MMBtu. Unfortunately, good clean burning fires that result in low LOI also tend to produce more NOx (See Figure No. 3). It was quickly discovered that the NOx level could be controlled by controlling excess air. However, how much was LOI being sacrificed when the total air was reduced enough to consistently maintain NOx levels below the permit limit? To monitor the carbon content in the flyash a high volume flyash flue sampler (Figure No. 4) was used during each test and the samples were screened through a 200 mesh screen and were then analyzed for fine particle LOI (passing through screen) and coarse particle LOI (remaining on screen). Initial test results showed the fine particle LOI was greater than the targeted 2% which indicated a need to improve furnace mixing and to introduce more oxygen into the burner area. By balancing the oxygen profile from side to side and bringing more air into the burner zone, the fine particle LOI's were eventually reduced to less than 2%. Coarse particle LOI was also above desired levels of 6% which indicated possible pulverizer related problems.

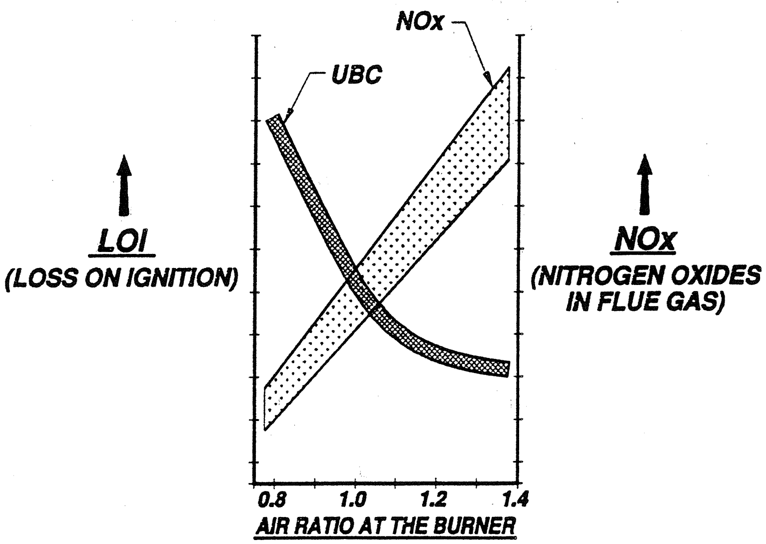
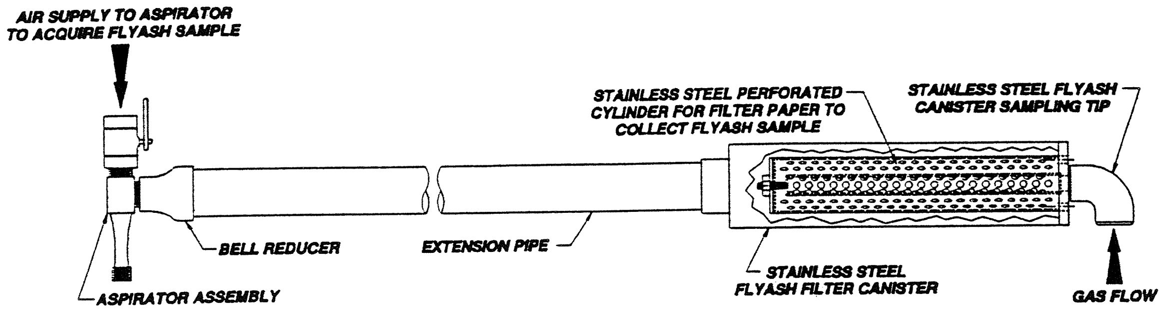


Figure No. 3 (Typical Relationship of Flyash Carbon Content & NOx)



HIGH VOLUME FLYASH SAMPLER

Figure No. 4

Pulverizer Testing and Optimization:

Consistent coal fineness of at least 75% passing 200 mesh with no more than 0.1% remaining on 50 mesh was the ultimate performance goal for the pulverizers. During testing, coal samples were taken from each burner transport line using a modified ASME type isokinetic sampler and a dirty air probe (Figure No. 5 and 6). Test ports were installed on the transport lines so the sampling and velocity measurements could be done on vertical runs from two axes 90° apart. The dirty air velocities were measured first in each fuel line to establish the proper sampling rate and air flow. Once the dirty air velocity traverse was complete, sampler orifice differential pressure was calculated and the isokinetic coal samples were taken. The isokinetic samples were then weighed to determine line to line coal distribution. After weighing, the samples were then sifted through 50, 100, 140, and 200 mesh screens to establish the coal fineness. Initial testing revealed that very poor and very good fineness results could be achieved with the Williams pulverizers depending on the particular set up of the mill. However, due to pulverizer control limitations the good results could not be consistently repeated. It was also known that some of the mill inconsistencies were due to primary air (PA) flow measurement errors.

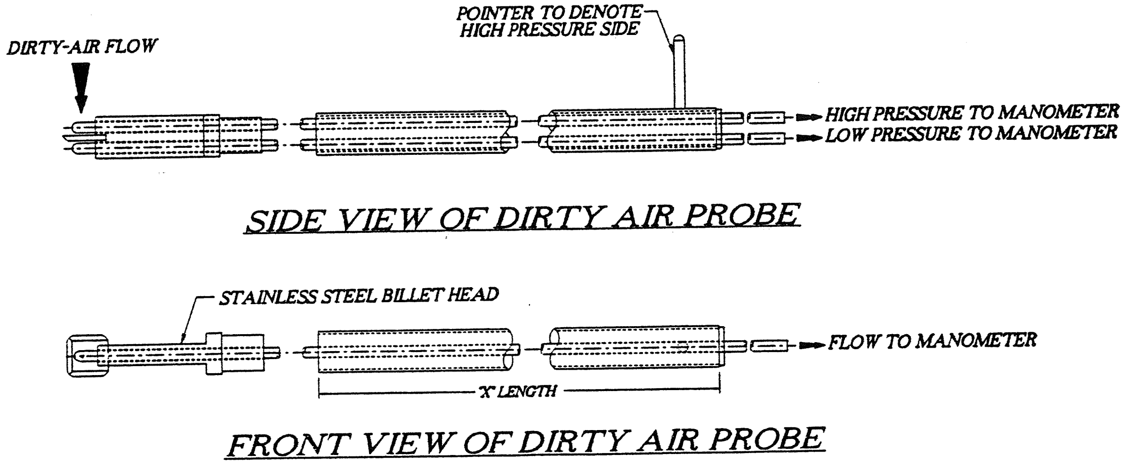


Figure No. 5

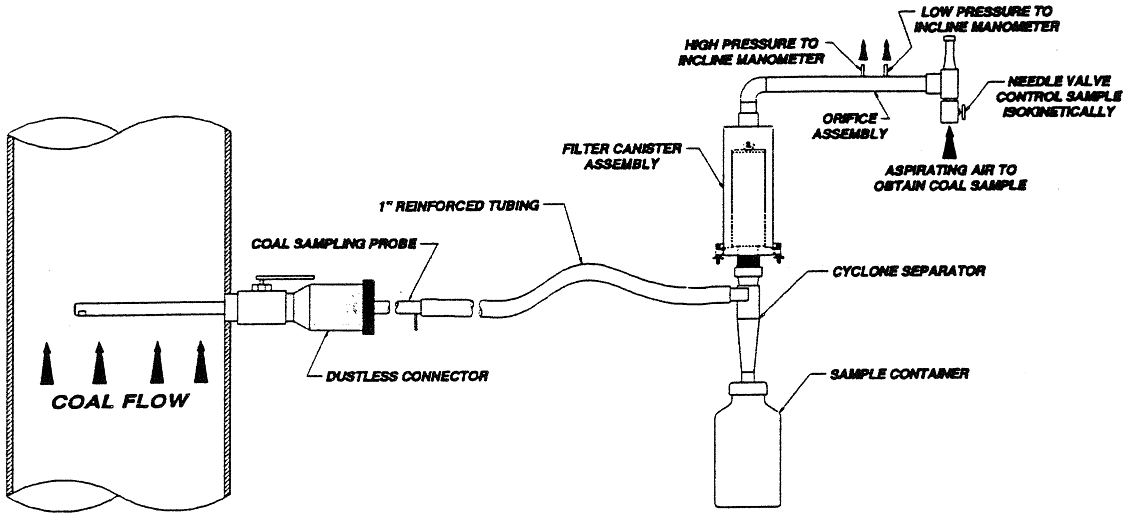


Figure No. 6

The pulverizers are equipped with variable speed mill and spinner drives. The original control of the pulverizers interfaced with the plant DCS for start and stop control only, while all other control functions were handled by a separate PLC. In order to enhance the operation of the pulverizers and achieve the necessary control of the spinner and pulverizer drives, the operator elected to modify and transfer the controls to the DCS. The operator's personnel developed new DCS logic and implemented the control swap-over on one of the pulverizers in December 1994. This modification followed on the remaining five pulverizers in March 1995. These control enhancements allowed the operator to develop new pulverizer drive and spinner drive curves which could be easily biased as operating or fuel conditions changed. These changes provided for finer control of the mills resulting in more consistent coal fineness throughout the load range. The changes also gave the operator more effective control of the pulverizer differential pressure which resulted in more uniform coal delivery to the boiler. Upon completion of these changes and fine tuning of the pulverizers, the composite LOI (Loss On Ignition) was reduced to less than 3%. To verify uniform fuel distribution within the range of ±10% burner to burner, the sample weights collected from the two burner lines were compared for each pulverizer. The coal sample weighing did verify the close relationship between coal fineness and fuel line distribution. Coal fineness in the targeted range resulted in more uniform distribution to the burners than did poor fineness coal. Based on the clean air test results, it was determined that no mechanical means of fuel line balancing would be necessary. The testing process also included recording all the necessary data to calculate air mass flow rate so the individual burner air to fuel ratio could be determined. A clean air flow test using a standard Pitot tube was performed to verify air flow balance and actual primary air flow. The clean air test consisted of multi-point traverses of equal areas. Each line was traversed through two axes and the velocities were averaged. The testing was performed at normal operating conditions. Initial testing revealed no significant pipe to pipe differences during clean air testing. The clean air test did however verify that the station PA flow measurements were highly inaccurate.

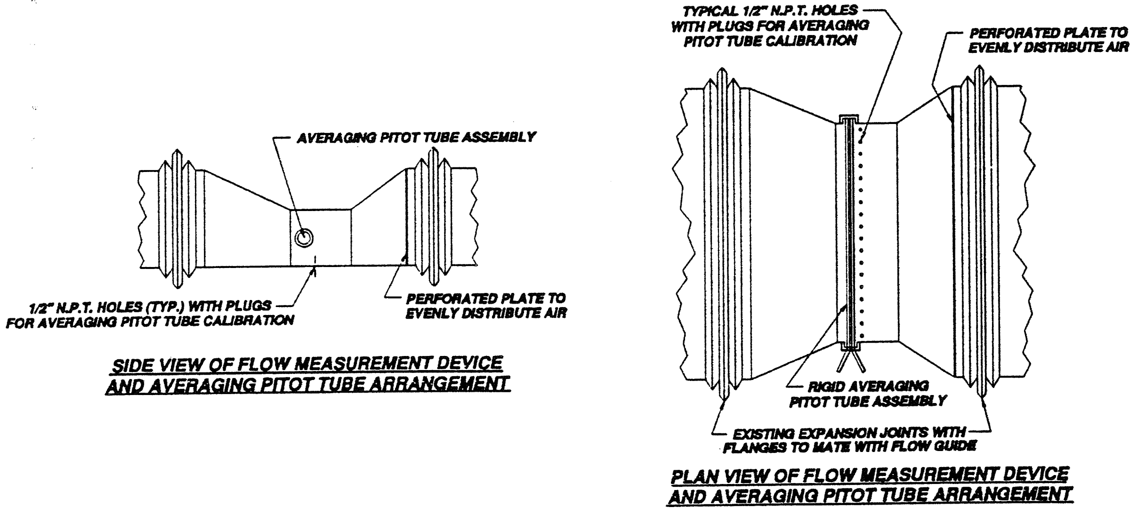
The PA flow indications were not accurate nor repeatable enough to provide optimum pulverizer control. "STORM" emphasized that there were multiple benefits to operating the pulverizers with an ideal air to fuel ratio of 1.8 pounds of air per pound of fuel. They are as follows:

- Stable burner performance
- Improved coal fineness
- Improved fuel distribution
- Reduced furnace exit gas temperature
- Reduced superheat spray flows
- Reduced flame impingement and increased waterwall life

- More complete combustion in the burner zone resulting in lower LOI
- Improved NOx control

At full load the boiler nominal primary air flow is approximately 16% of total boiler air flow. The fact that the Mecklenburg boilers suffered from excessive primary air flows proved to be one of the major contributing factors to the high superheat spray flows, poor coal fineness and high flyash LOI levels. This discovery was not easily correctable due to excessive pulverizer "rumble" and high differential operating pressures when the PA flow was initially reduced to the desired 1.8 to 1 air to fuel ratio. Improving the pulverizer controls by transferring them to the DCS and improving the PA flow measurement proved successful in overcoming these barriers.

Once it was determined that the primary air flow indication was not nearly accurate enough for precise mill tuning, a recommendation was made by "STORM" to modify the existing design to achieve a more accurate reading. The original installation used a pressure averaging pitot tube which only delivered a total span of 1" of water due to low duct velocities. The small differential pressure range coupled with a multi-leafed flow control damper immediately upstream resulted in the poor accuracy and repeatability that had been noted. "STORM" designed and fabricated new reduced area primary air duct sections with a pressure averaging pitot tube that provided up to 4" of water differential pressure at full load conditions (Figure No. 7). The increased velocity not only created more range from the pitot tube but the converging action of the reduced area duct resulted in more uniform velocities at the pitot tube. A flow distribution plate was designed from field pitot tube measurements to further enhance the uniformity of the air velocity profile at the pitot tube. The combination of the new duct sections and flow distribution plates resulted in measurements accurate to within ±3% compared to original measurements that were on the order of ±20%.



SIDE VIEW OF FLOW MEASUREMENT DEVICE AND AVERAGING PITOT TUBE ARRANGEMENT

PLAN VIEW OF FLOW MEASUREMENT DEVICE AND AVERAGING PITOT TUBE ARRANGEMENT

Figure No. 7

Accurate primary air flow indication was vital for the development of the primary air flow curves. These curves were developed along with the pulverizer drive speed curves and the spinner drive speed curves to meet the operational requirements of the pulverizers while maintaining the air to fuel ratio as close as possible to the ideal 1.8:1 over the entire pulverizer load range (Figure No. 8). Below 50% pulverizer capacity, the PA flow was limited by the minimum line velocity to prevent coal drop out and consequently the 1.8:1 air to fuel ratio could not be maintained. Actually mill "rumble" was more often the limiting factor on reducing PA flow to ideal conditions. This typically occurs at about 60% pulverizer capacity depending on the condition of the pulverizer. Below this load the PA flow must be increased somewhat above ideal to keep the coal bed lifted into the grinding zone and avoid excessive "rumble". This has not proven to be a major concern since at lower loads the boiler is more "forgiving" due to increased furnace residence time.

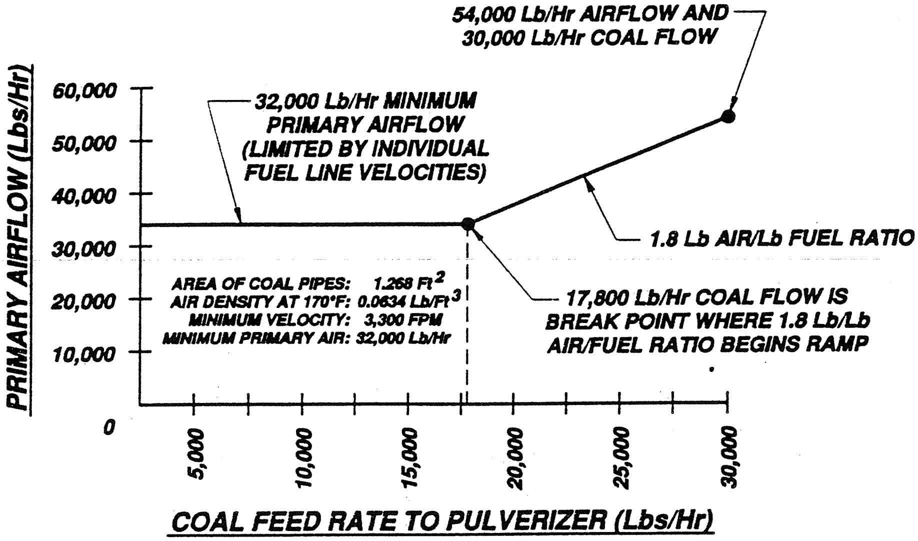


Figure No. 8

Burner Optimization:

Keeping a uniform and controllable secondary air flow at the burners also proved to be challenging. The initial setup of the burners following start-up only admitted air through the outer register. Consequently, the conditions in the burner area showed signs of insufficient oxygen and poor flame quality. The burners have a movable sleeve damper and an inner and outer register (Figure No. 9). The position of the sleeve damper, along with the windbox pressure, dictate the total air flow through the burner. The outer air register divides the secondary air stream into two concentric streams which independently vary air stream swirl. One air stream regulates the amount of air going to the inner air register and the other is directed by a flow divider to enter the furnace axially.

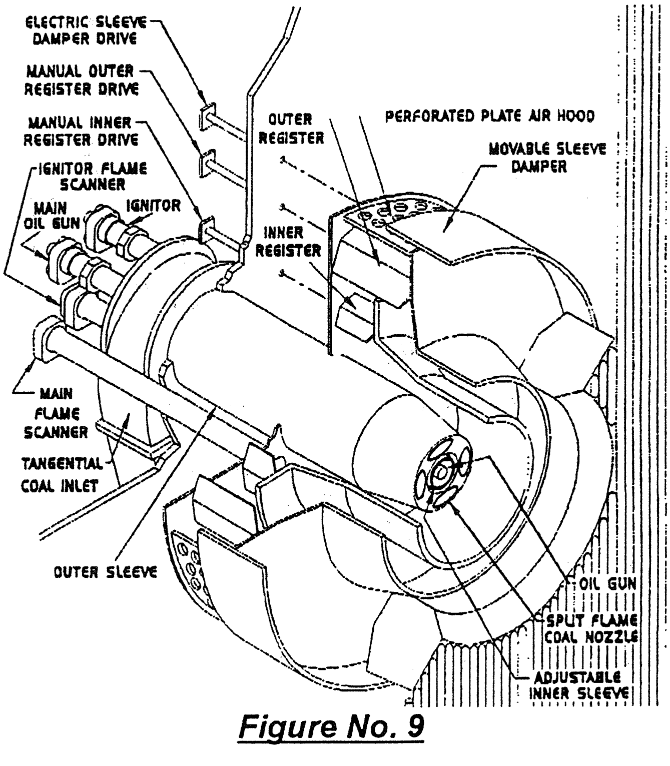


Figure No. 9

The swirl on the secondary air stream promotes sufficient mixing of the two streams to ensure adequate carbon burnout prior to exiting the flame zone. As the outer register is opened it transforms the flame from a bushy, short flame, to a longer, narrower flame. The inner register regulates the degree of swirl imparted on the coal/air mixture in the near throat area and, in conjunction with the primary airflow, controls the point of ignition of the mixture.

After a series of tests utilizing the HVT probe at the entrance to the superheater and visual observations, adjustments were made to improve the flame quality by positioning the sleeve dampers and air registers. This proved to be a very time consuming process which required close coordination. Due to a non-compartmented windbox adjustments that were made to any register had a cascade effect on the other registers and burners. The goal was to obtain an oxygen balance from side to side of 3% ±1% and NOx levels near the desired level of .32 lbs/MMBtu. Testing conducted on the overfire air ports showed significant air flow with the flow control dampers in the closed position. The original installation of the O.F.A. pitot tubes resulted in a very small differential pressure span with consequent poor accuracy. The ductwork in the area of the overfire airflow averaging pitot tube was modified to create a more uniform, repeatable, and accurate overfire airflow measurement. This was necessary for acceptable total airflow measurement and control.

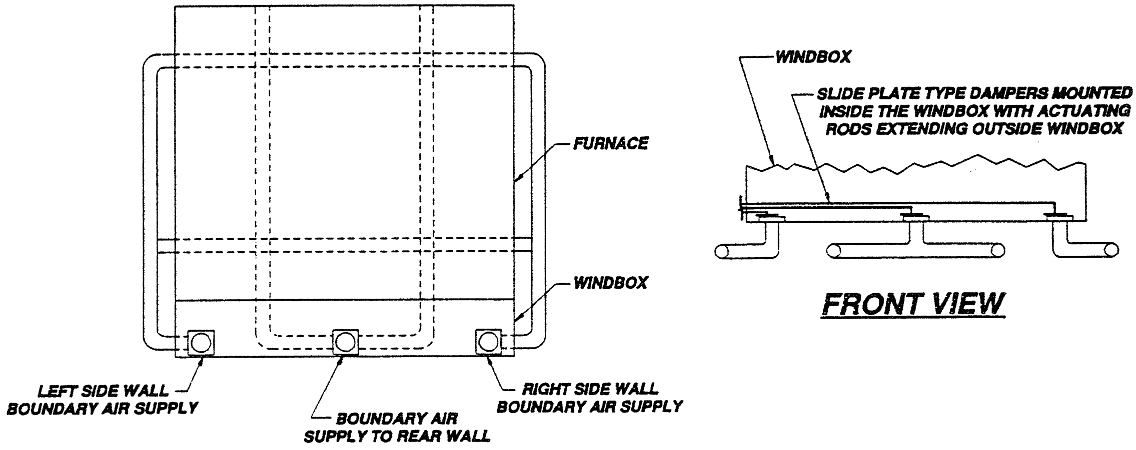
The boilers were also designed with a annulus around the bottom ash area to provide an oxygen blanket (boundary air) on the lower waterwall tube area to minimize reducing atmosphere metal wastage. The annulus is divided into three areas and is maintained at a positive pressure to allow small amounts of air flow through slots cut in the membrane between the lower tube sections. The lines coming out of the windbox for pressurization (Figure No. 10) initially had no means of throttling and no air flow indication. Dampers, which were designed and constructed on site, were installed in these lines to provide throttling. Testing was then conducted to limit and balance the amount of boundary air to achieve a good O_2 profile from front to back. This effort was intended to limit the amount of the total air entering the boiler at places other than through the burners. The following Table will show the results of the testing for the full load tests (Table No. 1).

Test No.	Avg. Excess Oxygen	Avg. Primary Air/Fuel Ratio	NOx (#/MMBTU)	O.F.A. (%)	* LOI (%)	Spray-Flow (#/H)	Peak Temp. (degrees F)	Efficiency (%)
1	2.59	2.06	0.366	0	26	67,000	2245	88.86
2	3.99	1.96	0.461	0	0.9	67,140	2175	87.64
6	1.53	1.95	0.308	100	26	79,010	2275	87.78
11	2.74	1.86	0.323	100	25	66,880	2216	88.11

** - Flyash Loss On Ignition as A Measurement of Carbon Content of Flyash*

Boiler Efficiencies measured by ASME P.T.C. 4.1 Short Form, Heat Loss Method

Table No. 1



PLAN VIEW

FRONT VIEW

Figure No. 10

Fuel Flow Verification:

During the optimization process it was also important to verify the tolerances of the feeders and verify smooth feed rates. The calibration of the feeders was verified prior to testing and data was recorded during the test to ensure smooth consistent operation of the feeders and their control. The calibrations were already part of the plants continuing preventive maintenance program which made this step one of the easiest.

CONTINUED IMPROVEMENT:

Following the initial testing and optimization phase a significant amount of progress had been made. The furnace exit oxygen had been reduced to an acceptable range of 3% with a good side to side balance. The LOI of the flyash was below 5% on a consistent basis. The de-superheater spray flows had been reduced from 79,000 lbs/hr to 67,000 lbs/hr, flame quality was consistent through the load range of the boiler and maintaining consistent, acceptable NOx levels were also possible.

The de-superheating spray water flows and furnace exit gas temperature tend to increase at high load factor operation. This is due to furnace seasoning, i.e., slagging from continous operation. The data in Table No. 1 was taken on a seasoned furnace. Provisions were made in the original design for waterwall deslaggers to be installed on the rear and side waterwalls. The installation of four are planned in the next year. The purpose of these are to increase furnace waterwall heat absorption and further reduce de-superheater spray water flows at high capacity operation. The operator was confident that if testing was conducted on a regular basis the improvements could be maintained and further improvements would follow. "STORM" recommended a continuing performance preservation program which included the following:

- Furnace exit excess oxygen and temperature traverses
- Economizer exit oxygen and temperature traverses
- Economizer exit flyash sampling
- Pulverizer burner line clean air test
- Pulverizer coal sampling for line balances and fineness
- Bottom ash observation for carbon content

The core group of operators that was assigned to the initial test group had become quite proficient with the sophisticated test equipment supplied by "STORM". The group was able to repeat the testing with enough confidence that the decision was made to purchase the test equipment. Following a brief procedure development period the testing was repeated on both units. The findings from successive testing resulted in the development of detailed procedures and a trouble-shooting guide describing how to operate the units efficiently over the entire load range, with different pulverizer combinations and while continuously maintaining compliance NOx levels. The procedures also outlined actions that could be taken during upset conditions to minimize the effects on plant efficiency while maintaining reliable operations until any such problem could be corrected.

The modifications that were made to the pulverizers and the primary air ducts have given the operators the ability to fine tune the boilers at all loads. To minimize the turnaround time of fineness results a shaker and the necessary coal fineness testing equipment was purchased. The test procedures that were developed promote testing by any member of the plant staff that may recognize a potential problem. A series of computer spreadsheets and files have been developed to allow for easy storage and retrieval of the test data. Various quality checks have been incorporated into the procedures to flag potential problems and to help ensure reliable results. These quality checks include using computer worksheets with all relevant formulas, to backup manual calculations done during the testing, the use of a proven method of fineness testing and plotting the results on a Rosin and Rammler Chart, and utilizing DCS trending during testing to document test conditions. The integration of the testing program with the current preventive maintenance program will provide improved pulverizer wear tracking and control curve tuning so the desired plant efficiency can be maintained throughout the pulverizer wear life. The advantages of developing and maintaining this history includes extended pulverizer life by not over-grinding the coal, reduced auxiliary loads, reduced maintenance costs and manpower savings.

In conjunction with the program development, the need was identified for more accurate boiler O_2 measurement to ensure proper excess air was maintained. Two Yokogawa oxygen monitors were installed in the boiler before the economizer. One monitor was placed on each side of the boiler (at the same spacing as the burners) so the side to side oxygen profile could be taken, averaged and used for the boiler O_2 control signal. The DCS allows for individual monitoring which helps the operator recognize possible problems before they have a major impact on the plant. Aligning the monitors with the burners assists the operator with identifying burner imbalance problems. At the time of this writing O_2 control curves were under development which will be incorporated into the DCS for precise air flow control over the entire load range.

SUMMARY:

The success of the optimization program was the result of a proactive commitment by the owners and operator. Changes were implemented using a fast track approach so benefits could be realized quickly. The success of the program was related to the implementation of changes in design, early in the operating life of the units. The key factors in the success were:

- Completing a comprehensive combustion system analysis and identifying the optimization program goals to provide focus for all parties.
- Team approach of owners, operator, and consultant to work together for the overall best performance.
- Rapid approval of capital expenditures for changes
- Expedited and smoothly coordinated implementation of changes utilizing strong teamwork from all parties involved.
- Development of operating personnel's awareness of factors regarding performance, maintainability, load response, capability and reliability.
- Establishment of routine follow-up testing and tuning to preserve the performance gains.

The capital expenditures which have been implemented so far are:

- DCS control of pulverizers
- Purchase of boiler test equipment
- Installation of new primary airflow measuring duct sections on all pulverizers.
- Installation of two new permanent oxygen analyzers per boiler.

Capital expenditures planned for next year for continuing performance improvement are:

- Installation of waterwall de-slaggers.

Heat rate gains from the optimization program cannot be quantified due to the lack of a complete thermal performance kit for these units at the time of the boiler optimization. The reduction in ash disposal costs from reduced ash production has been significant in itself. Boiler flame stability has been greatly increased through the performance improvement efforts. Plant reliability has been excellent with an Equivalent Forced Outage Rate (EFOR) of 0.7% in 1994 and 0.5% year to date in 1995. The bottom ash now has a consistent light gray color, flyash LOI's are less than 5% at all loads and NOx control is predictable, reliable and comfortably within permit limits. Due to the high level of employee involvement throughout the optimization process, the awareness level is now very high. Most combustion problems are quickly recognized and corrected by operating personnel.

The commitment of the owners and operator to actively support a team approach is the primary reason for the success. The writers wish to acknowledge our fellow team member's contributions to this project. Too many people were involved to name all individuals in the space provided. The principal participants are: The Duke/Fluor Daniel Mecklenburg team, the owners consisting of American National Power and Duke Energy Corp., and Storm Technologies, Inc. The authors gratefully acknowledge the participation and contributions of all personnel who were involved.