CONTROLLING NO_x EMISSIONS AT PSI ENERGY'S WABASH RIVER UNIT 2

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ABSTRACT

PSI Energy installed a new low NO_x combustion system in their Wabash River Station Unit 2 to meet pending regulations of the 1990 Clean Air Act. The unit is rated for 700,000 pph steam flow (100 MW) and burns Indiana bituminous coal. NO_x emission requirements were < 0.45 lb/10^6 Btu which represented at least 50% reduction from uncontrolled NO_x emission levels.

This paper discusses the design, installation and performance testing results of the new low NO_x combustion system supplied by Riley Stoker Corporation. Post retrofit performance showed that NO_x emissions could be effectively controlled to below 0.45 lb/10^6 Btu with acceptable boiler performance. Data presented includes both emissions analysis at the boiler outlet as well as in-furnace measurements of O_2 and CO emission levels. The impact of the new low NO_x system on overall boiler operation will also be discussed.

INTRODUCTION

PSI Energy is an investor owned utility serving the central and southern regions of Indiana. The gross generating capacity from pulverized coal fired boilers is 5975 MW. PSI Energy has always strived to be an environmentally responsible corporation. Since the passage of the 1990 Clean Air Act, PSI Energy has implemented several projects to control flue gas emissions from their boiler plants.

One of the major projects initiated in the spring of 1992 was to reduce NO_x emissions from the Wabash River Station, located in Terre Haute Indiana. The station is equipped with five (5) wall fired and one (1) tangential fired boilers. All boilers burn a high volatile bituminous coal. The five (5) wall fired units were designed and built in the early 1950's. The tangential fired unit was built in the mid 1960's. Total generating capacity from the Wabash River Station is 805 MW.

This paper discusses the design, installation and performance testing results of retrofitting Unit 2 of the Wabash River Station with a new low NO_x combustion system supplied by Riley Stoker Corporation. The new combustion system included low NO_x burners, an overfire air system and control system modifications.

UNIT DESCRIPTION

Wabash River Unit 2 of PSI Energy is a coal fired utility boiler, originally designed and constructed by Foster Wheeler Energy Corporation in the early 1950's. The steam generator, located in West Terre Haute, Indiana, produces steam at 700,000 lb/hr, 1005°F/1005°F superheat and reheat temperature and 1500 psig operating pressure. The furnace dimensions are 44'-8" W x 22'-2" D.

The unit, shown in **Figure 1**, was originally rated to generate 100 MW of electrical power. However, because of coal quality and station emission limits, the unit typically operates at 85-90 MW.

Pulverized coal is supplied by two (2) size D-7 ball tube mills with exhauster fans which feed twelve (12) burners arranged in two (2) rows of six (6) burners per row. Wabash Unit 2 burns a high volatile bituminous coal from Indiana.

LOW NO_X COMBUSTION RETROFIT

Figure 2 shows a drawing of the complete low NO_x combustion system retrofit which included low NO_x burners and an OFA system. The following describes the primary equipment supplied and work performed.

Low NO_x Burners

Twelve (12) new low NO_x CCV® burners were installed on the front wall. The CCV® burner, shown in **Figure 3**, is a single register swirl stabilized low NO_x pulverized coal burner which Riley has been supplying to the industry since the early 1980's (1).

The basic CCV® burner design and theory of operation has been reported extensively in previous technical papers (2, 3). The latest design enhancement, which was retrofitted one year ago to the Wabash Unit 2 burners, is the secondary air diverter, shown in **Figure 3**. The diverter causes the secondary air to initially flow away from the primary combustion zone, creating a large reducing zone immediately at the burner discharge. This promotes rapid devolatilization of the coal in a reducing environment which contributes to significant NO_x reduction. The secondary air blends into the coal flame downstream of the primary combustion zone to complete the combustion process.

Recirculation eddies created on the backside of the diverter helps to intensify ignition of the coal thus promoting the devolatilization process. The diverter maintains a well attached pulverized coal flame with good ignition close to the coal nozzle tip for several different coal spreader designs and fuel properties. This flexibility allows for excellent NO_x control over a wide range of operating conditions and fuel characteristics.

Pilot scale test results last year in our research laboratory have shown a significant improvement in CCV® burner performance with the new secondary air diverter (4). The secondary air diverter improves NO_x control during unstaged firing by 25-30%. During staged firing ($SR_B < 1.0$) this improvement decreases to 10%. The testing showed the potential for the CCV® burner to reduce NO_x emissions > 60% without the need for OFA ports.

Overfire Air System

A total of ten (10) overfire air ports were installed on the front wall above the burners on Wabash Unit 2. Five (5) ports were installed in each furnace cell since the furnace was divided in half by a division wall. One (1) port was located above each burner column and "wing" ports were installed between the side OFA ports and side waterwalls or partition wall. Wing OFA ports were found, from flow model studies performed by Riley in the mid 1980's for EPRI (5), to be extremely beneficial for enhancing mixing effectiveness.

The OFA ports were also divided into 1/3 and 2/3 sections with automatic flow control dampers in order to maintain the proper OFA penetration throughout the boiler load range. The 1/3 and 2/3 dampers were programmed to automatically open and close at various load points to ensure the proper amount of OFA and penetration velocity is maintained throughout the load range.

The OFA ports were constructed to be internal within the secondary air ducting as shown in **Figure 3**. The system was designed to enable staging as low as 0.90 burner zone stoichiometry. However, as discussed later, acceptable NO_x levels were achieved while operating with a burner zone stoichiometry above 1.05.

Control System Modifications

Each CCV® burner shroud was equipped with a modulating type linear actuator. The burner shrouds were modulated as necessary to automatically control windbox to furnace ΔP to follow a predetermined boiler load based set point. The set points ranged from 4" wg at full load to 1.5" wg at 50% boiler load.

Overriding this automatic control was the ability to manually position the burner shrouds to various "full open" positions in an attempt to balance the excess air side to side through the unit. This was quantified by measuring excess O_2 at the economizer outlet using sixteen (16) point sampling grids installed in both left and right outlet ducts.

Each OFA port was equipped with two (2) sections (1/3 and 2/3 area split) and individual control dampers in each section. The dampers were connected together and operated through common shafts by low speed electric actuators. All the 1/3 and 2/3 ports were opened or closed simultaneously following commands from boiler load (steam flow) as follows:

< 70% MCR	1/3 Closed, 2/3 closed
70-90% MCR	1/3 Open, 2/3 Closed
91-100% MCR	1/3 Closed, 2/3 Open

These load points were established during characterization and optimization testing following the boiler retrofit. As discussed later, it was determined that full OFA flow (1/3 and 2/3 open) was not required to achieve acceptable NO_x levels. Again, this was attributed to the additional benefits of secondary air diverters.

TEST RESULTS

As indicated earlier, the goal of the retrofit project was to reduce NO_x emissions from Wabash River Unit 2 to < 0.45 lb/10^6 Btu. Baseline testing of Unit 2, to quantify pre-retrofit emission levels, was not performed. However, baseline testing was performed on Unit 4, an identical unit to Unit 2. Uncontrolled NO_x levels measured at 77 MW or 77% MCR load from Unit 4 averaged 0.95 lb/10^6 Btu. This indicated > 50% reduction in NO_x was required to meet acceptable performance on Unit 2.

December, 1992 Testing

Post-retrofit performance testing conducted in December, 1992 showed that the new combustion system was capable of controlling NO_x emissions to < .45 lb/10^6 Btu with only a minor amount of OFA. As shown in **Figure 4**, acceptable emission levels were achieved while operating with burner zone stoichiometric ratios, SR_B above 1.0. **Figure 5** shows how NO_x emissions can be controlled to a relatively constant level with variations in boiler load.

CO emissions and flyash unburned carbon were higher than expected. CO emissions at the economizer outlet averaged 150 ppm but were generally very erratic. Flyash unburned carbon averaged 8-10% which was also higher than expected.

Subsequent testing of the milling system indicated the primary air to coal ratio, A/C, was significantly higher than anticipated mostly due to air in-leakage of the suction type mill system and exhauster fans. Consequently, the burner nozzle velocities exceeded our design standards which in turn affected burner performance. This could potentially contribute to the higher than expected CO emissions and flyash unburned carbon.

The December, 1992 testing also revealed a significant O_2 maldistribution existed at the economizer outlet possibly due to air infiltration or leakage through the boiler casing. This also could have contributed to the relatively high CO and unburned carbon. Burner shroud biasing in an attempt to minimize this distorted O_2 profile was only marginally effective. Subsequent testing was then performed in March, 1993 to further investigate this problem.

March, 1993 Testing

Diagnostic testing was performed to investigate the "U" shaped oxygen profile measured at the economizer outlet during the December testing. A possible cause was air infiltration particularly on a boiler nearly 40 years old. The test procedure called for measuring oxygen profiles in the upper furnace through observation doors 2, 4 and 5 using 20' water cooled high velocity thermocouple, HVT probes. These measurement locations are shown in **Figure 6.** The profiles were then compared to similar profiles measured at the economizer outlet.

Figure 7 shows a summary of O_2, CO and NO_x profiles measured in the upper furnace through the selected observation doors and at the economizer outlet. The O_2 profiles measured in the upper furnace were convex or shaped like an inverted "U" while a concave or "U" shaped O_2 profile was detected at the economizer outlet. This was typical for all the tests performed. An average O_2 reading increase of 0.6% was recorded from the upper furnace to the economizer outlet. This corresponds to 4% in-leakage rate. The flip-flop in the profile along with the increase in O_2 concentration confirmed the unit was experiencing air infiltration.

This air infiltration problem leading to the O_2 maldistribution was also measured on Unit 4 prior to the installation of low NO_x burners. This was apparently a pre-existing condition prior to the retrofit of Unit 2. More recent testing has indicated the furnace air infiltration can be as high as 8-12%. Casing and ductwork repairs on all the Wabash units are currently being implemented.

Despite the O_2 maldistribution, both NO_x and CO emissions were low. Also, of significance was the fact that the CO emissions were much lower than measured during the December, 1992 testing. CO levels were recorded to be < 20 ppm during the March, 1993 testing. Burner shroud biasing during the March, 1993 testing was more aggressive than the December, 1992 tests in an attempt to balance the O_2 distribution. This had a significant benefit in minimizing CO as well as flyash unburned carbon. As shown in **Figure 8**, with the burner shrouds biased, flyash unburned carbon averaged 8.2% at 85% load. When burner shrouds were not biased unburned carbon increased to nearly 13%. Unburned carbon prior to the retrofit was estimated to be 8-10% at 85% load. The CCV® burners reduced NO_x without a significant change in flyash unburned carbon.

Table 1 summarizes the data comparing pre-retrofit to post retrofit boiler testing while **Table 2** shows the fuel analysis. Results showed that NO_x emissions could be significantly reduced without adversely impacting overall boiler performance. We anticipate further improvements in flyash unburned carbon following the installation of new coal nozzles in the fall.

The testing did emphasize the importance of fully understanding the complete fuel burning system including mill operation prior to the design of a low NO_x retrofit. Significant items learned from this testing included:

- Primary air to fuel ratio A/F is critical for proper design and selection of low NO_x burners. Riley Stoker's current approach in the design of low NO_x retrofit systems is to first measure the actual primary A/F ratio which the milling system is operating at. This information is then used for properly sizing the CCV® burner coal nozzle.

- Low NO_x burners need to have the capability of biasing secondary air flow in order to balance O_2 and CO distribution at the boiler exit.

- Furnace in-filtration could become a significant hindrance for low NO_x burners if the burner design lacks flow biasing capability.

EFFECTS ON BOILER OPERATION

As a result of retrofitting Wabash River Unit 2 to low NO_x operation more than a year ago, the unit has not experienced a significant change in boiler operation. If anything, boiler efficiency and reliability have improved. The plant reports no noticeable change in slagging and fouling characteristics. Normal sootblowing practices continue to be followed. Maintenance of the new burner equipment has not been required during the period of operation other than replacing worn coal spreaders. No mechanical problems with the burner or OFA equipment have been experienced. Waterwall corrosion has not been an issue.

A extensive operator training program was provided in 1992 prior to unit startup. Recently, a second extensive operator training program was provided as part of the burner replacement projects for Units 3 and 4. Operators are beginning to pay close attention to the efficient operation of all the Wabash units. A better understanding of burner shroud control philosophy has shown significant improvement in Unit 2 performance on a daily basis. The new CCV® burner equipment is performing as expected.

SUMMARY

PSI Energy has successfully retrofitted low NO_x combustion technology on Wabash River Unit 2. Of particular importance was the ability of the new combustion system to achieve NO_x emissions < 0.45 lb/10^6 Btu without degradation in boiler performance despite problems experienced with furnace air infiltration or leakage. Independent control of the burner equipment was necessary to compensate for this leakage and achieve acceptable performance. The burner shrouds and OFA dampers were all easily controlled from the control room. Boiler operation was not adversely affected with the new equipment installed. Mechanical reliability has improved.

Plans for the future are to install larger coal nozzles early this fall in Unit 2 to compensate for the higher than anticipated primary air to fuel ratios from the milling system. This should help to improve combustion efficiency and further reduce flyash unburned carbon. Testing of the unit will commence shortly after. Unit 4 is currently being retrofitted this fall with the same equipment supplied by Riley Stoker Corporation while Unit 3 will be retrofitted next spring.

Acknowledgements

Special thanks are extended to Chris Clemmer, Riley Stoker's resident service engineer at the Wabash River Station for his significant contributions to this paper. His day to day observations of the boiler operation at this plant have been extremely beneficial regarding the long term effects of low NO_x retrofits. Also, thanks are extended to Brian Vitalis, Associate Engineer, Riley Stoker Corporation, for his contributions regarding the data reduction and analysis for this project.

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Table 1
PSI Wabash Unit 2
Emissions Test Results

Test	Baseline[1]	Post Retrofit
Burner Design	FW - Intervane	Riley - CCV®
Load, %	77	89
OFA, %	0	13
NO_x, lb/10^6 Btu	.9 - 1.0	.38
CO, PPM	< 10	10 - 180
Flyash UBC, %	8	8 - 9
THC, PPM	-	4 - 10
Econ. Gas Out Temp. °F	561	590
A H Gas Out Temp. °F	267	264
Coal Fineness		
% - 50 Mesh	-	98.9 - 99.2
% - 200 Mesh	-	78.7 - 84.5

(1) Based on testing Unit 4, identical design to Unit 2.

Table 2
PSI Wabash Unit 2
Fuel Analysis

H_2O (%)	12.90
VM (%)	31.30
FC (%)	44.40
Ash (%)	11.40
C (% dry)	69.30
H (% dry)	4.80
O (% dry)	9.43
N (% dry)	1.27
S (% dry)	2.10
HHV (Btu/lb)	10,832

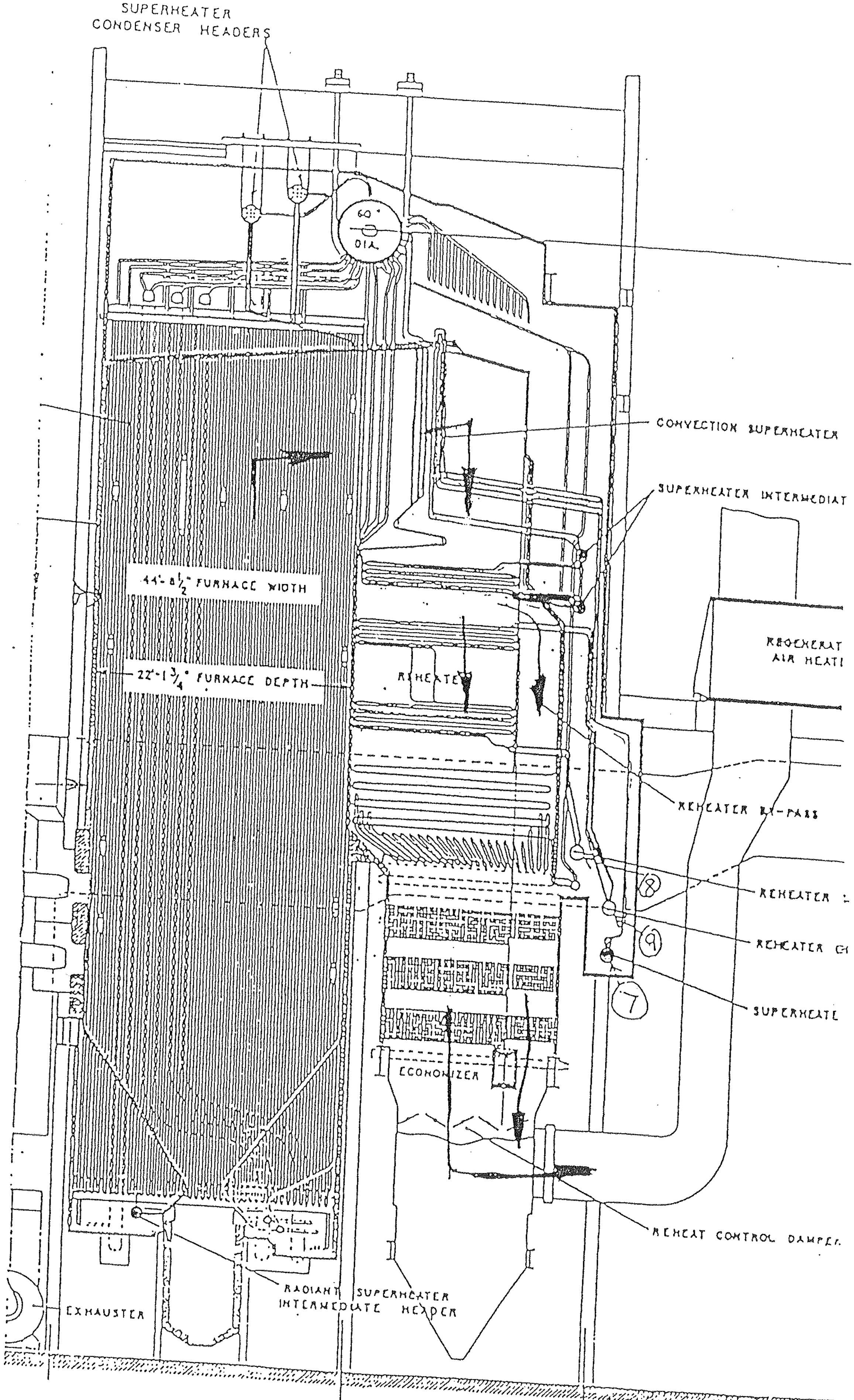


Figure 1. PSI Wabash Unit 2 Original Boiler Configuration

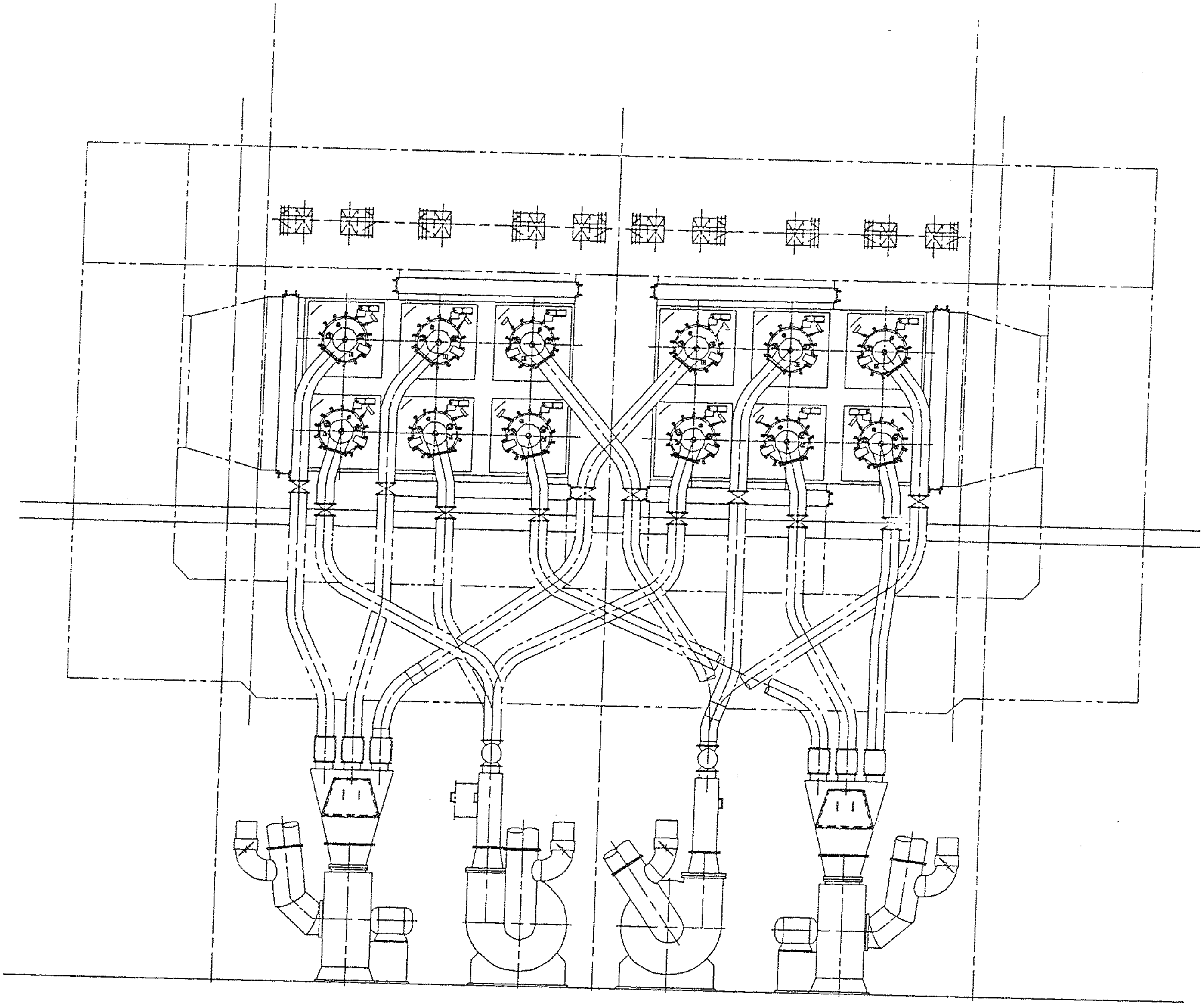


Figure 2. Low NO_x Combustion System Retrofit for PSI Wabash Unit 2

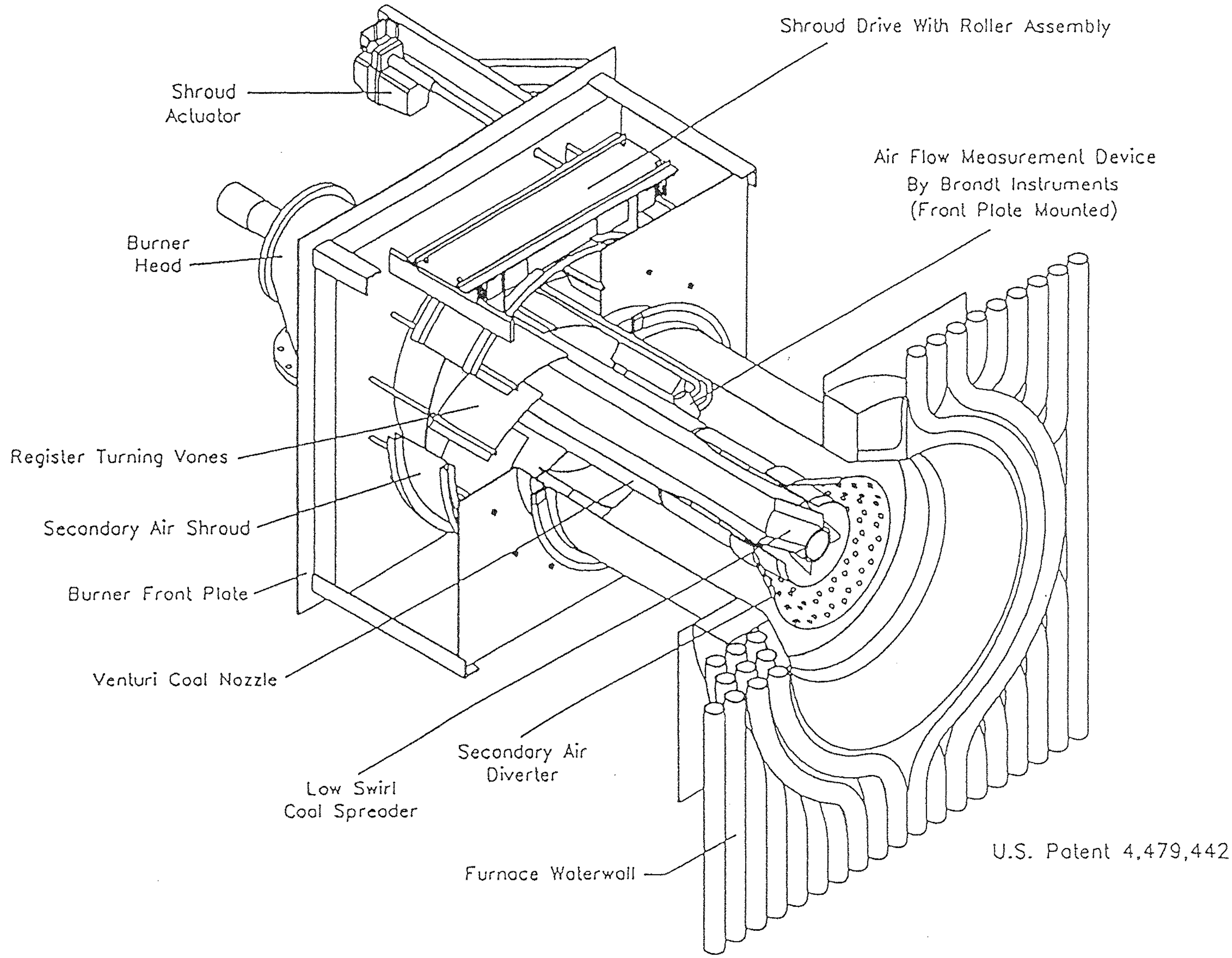


Figure 3. Riley Low NO_x CCV® Burner with Secondary Air Diverter

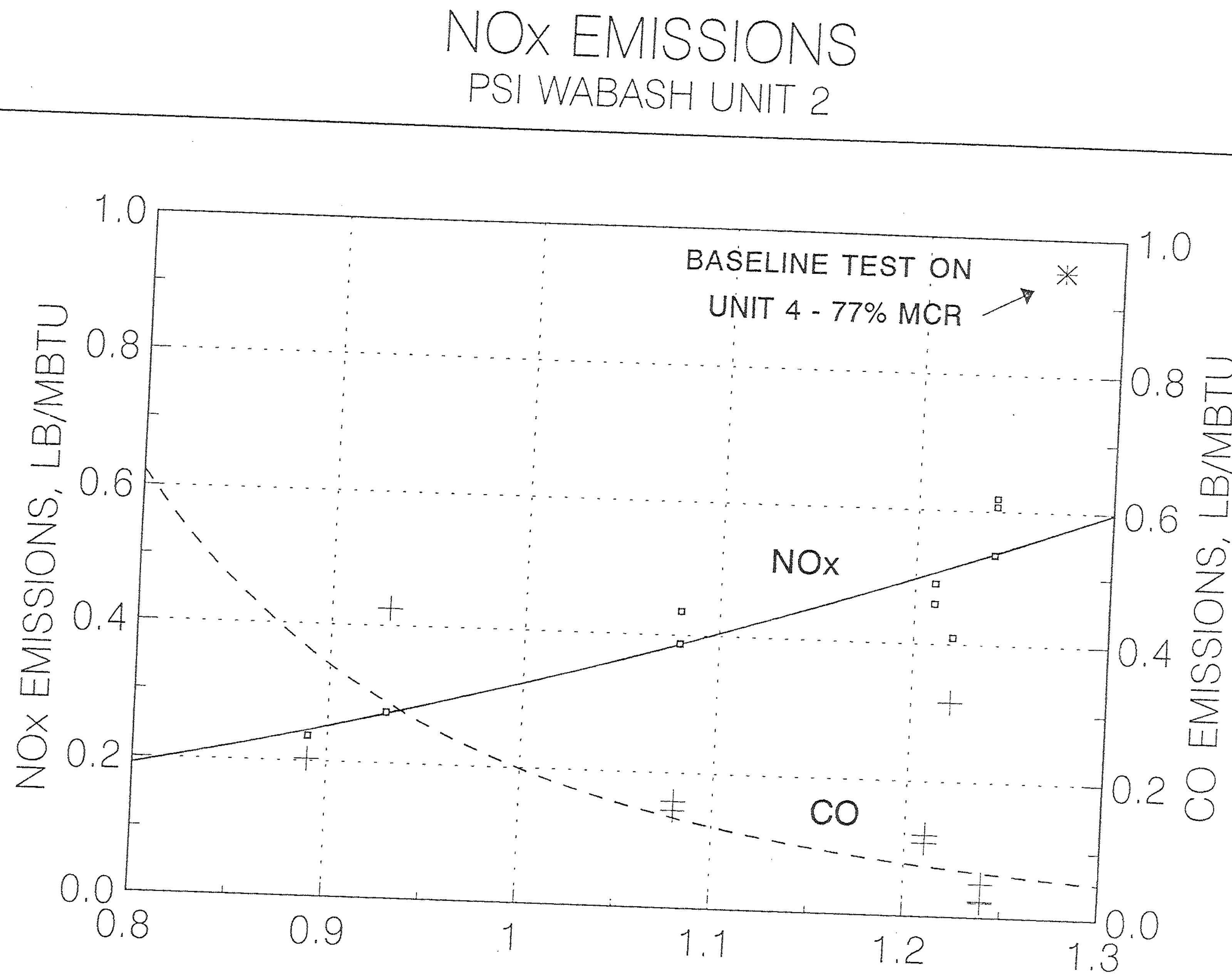


Figure 4. The Effect of Air Staging on NOx and CO Emissions

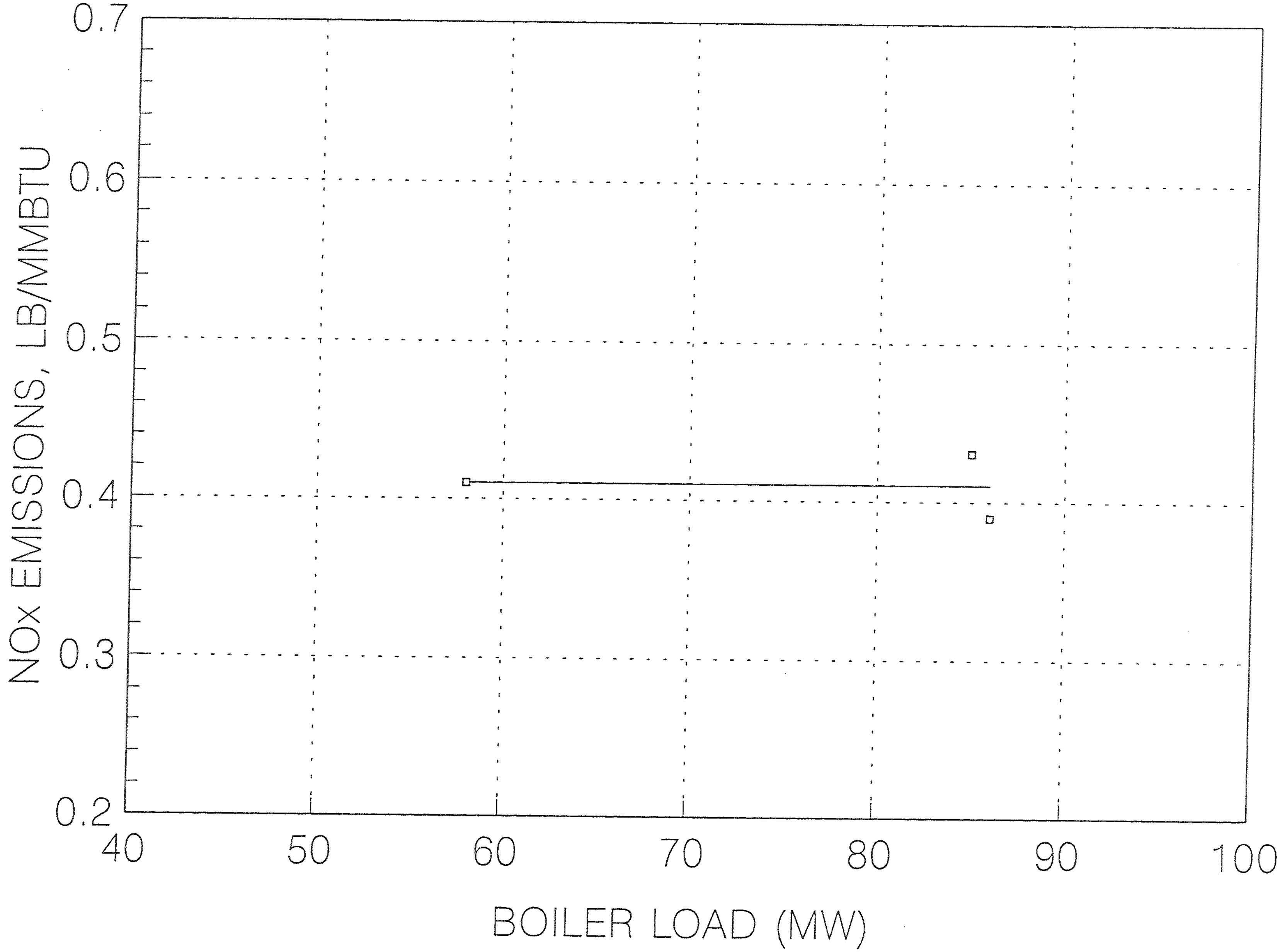


Figure 5. The Effect of Boiler Load on NO_x Emissions

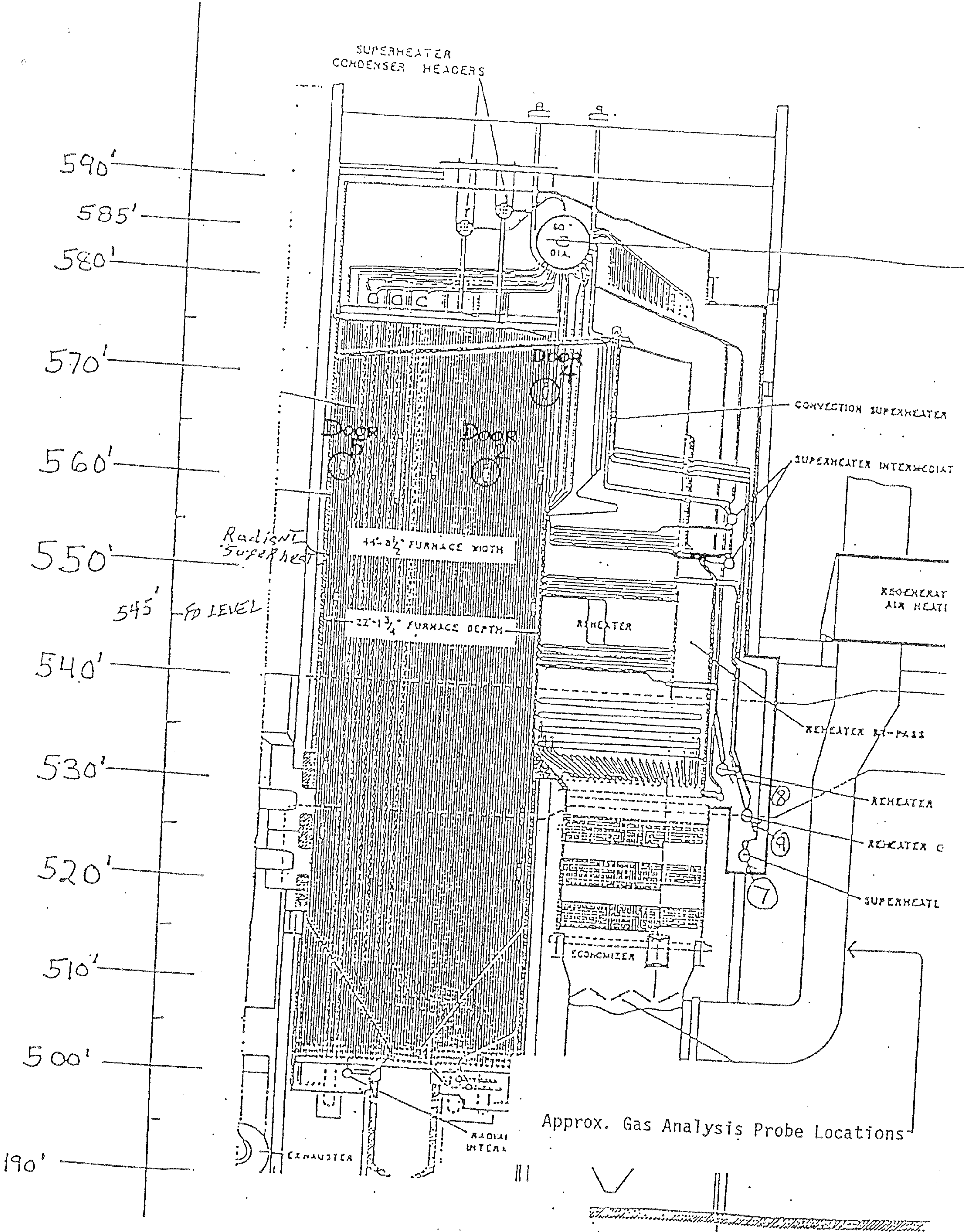
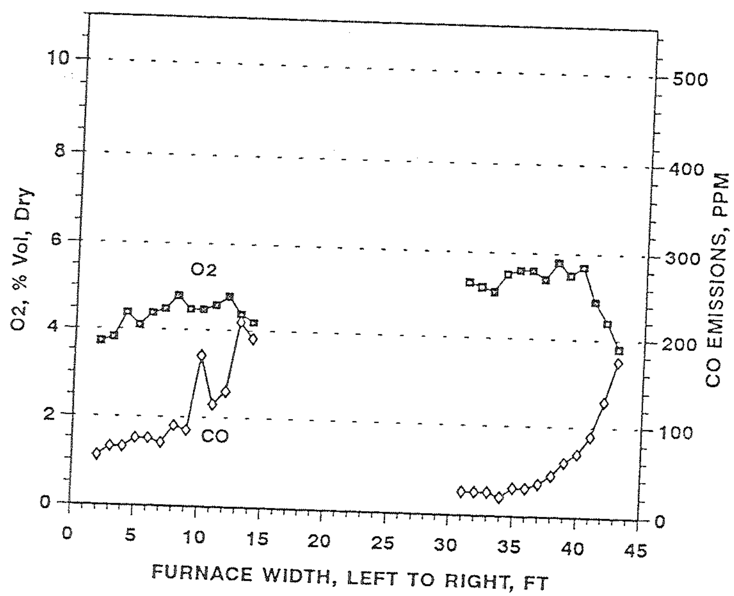
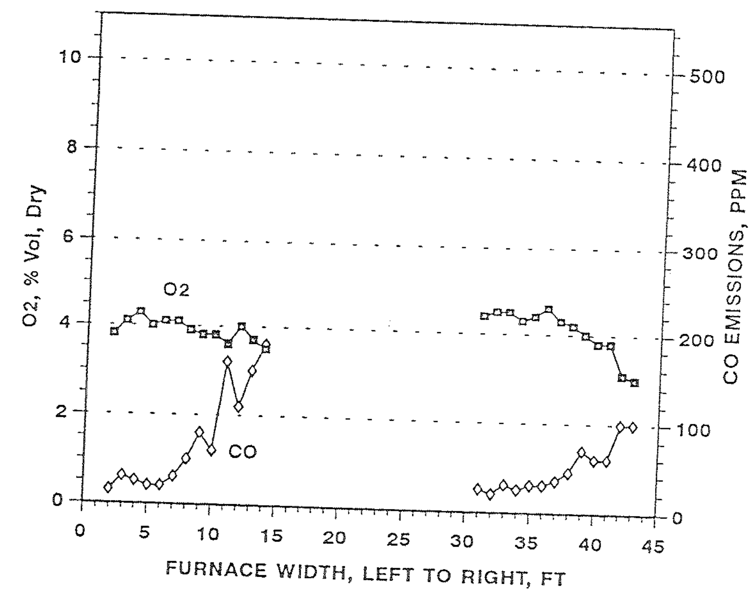


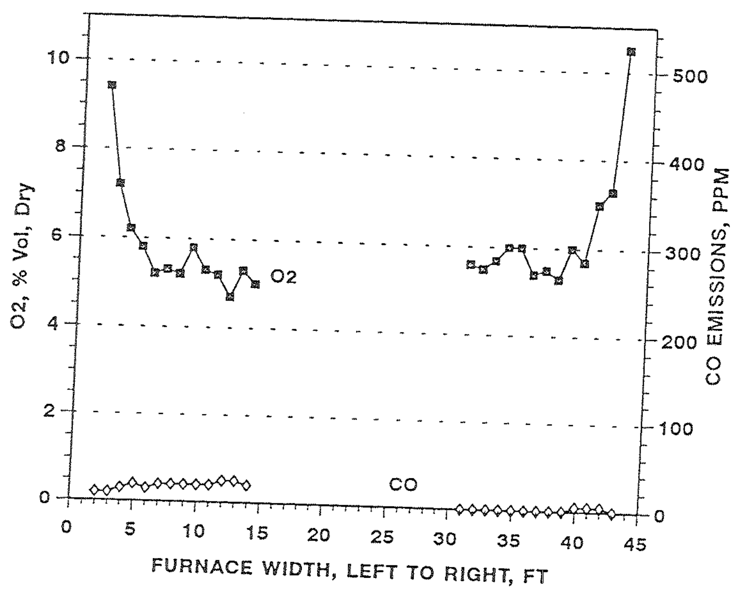
Figure 6. Upper Furnace Measurement Locations



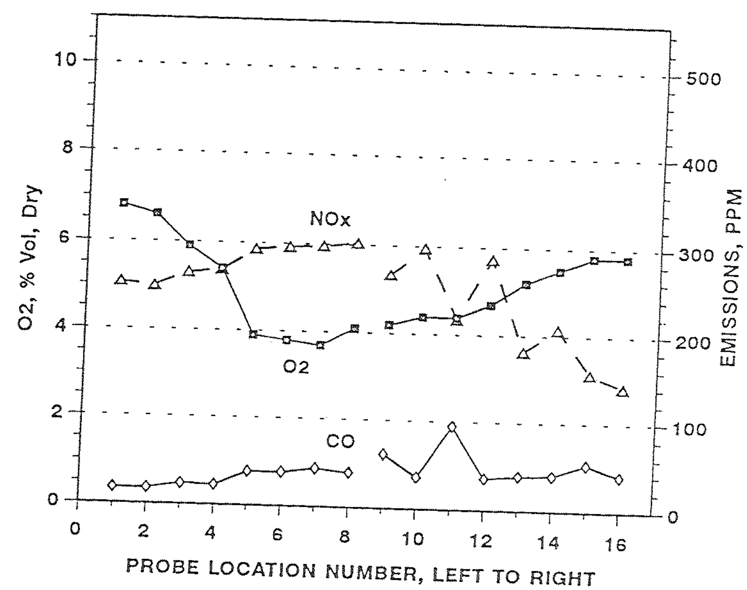
Furnace Emissions Profiles, Door #2



Furnace Emissions Profiles, Door #4



Furnace Emissions Profiles, Door #5



Emissions Profiles at Economizer Outlet

Figure 7. Furnace Emission Profiles

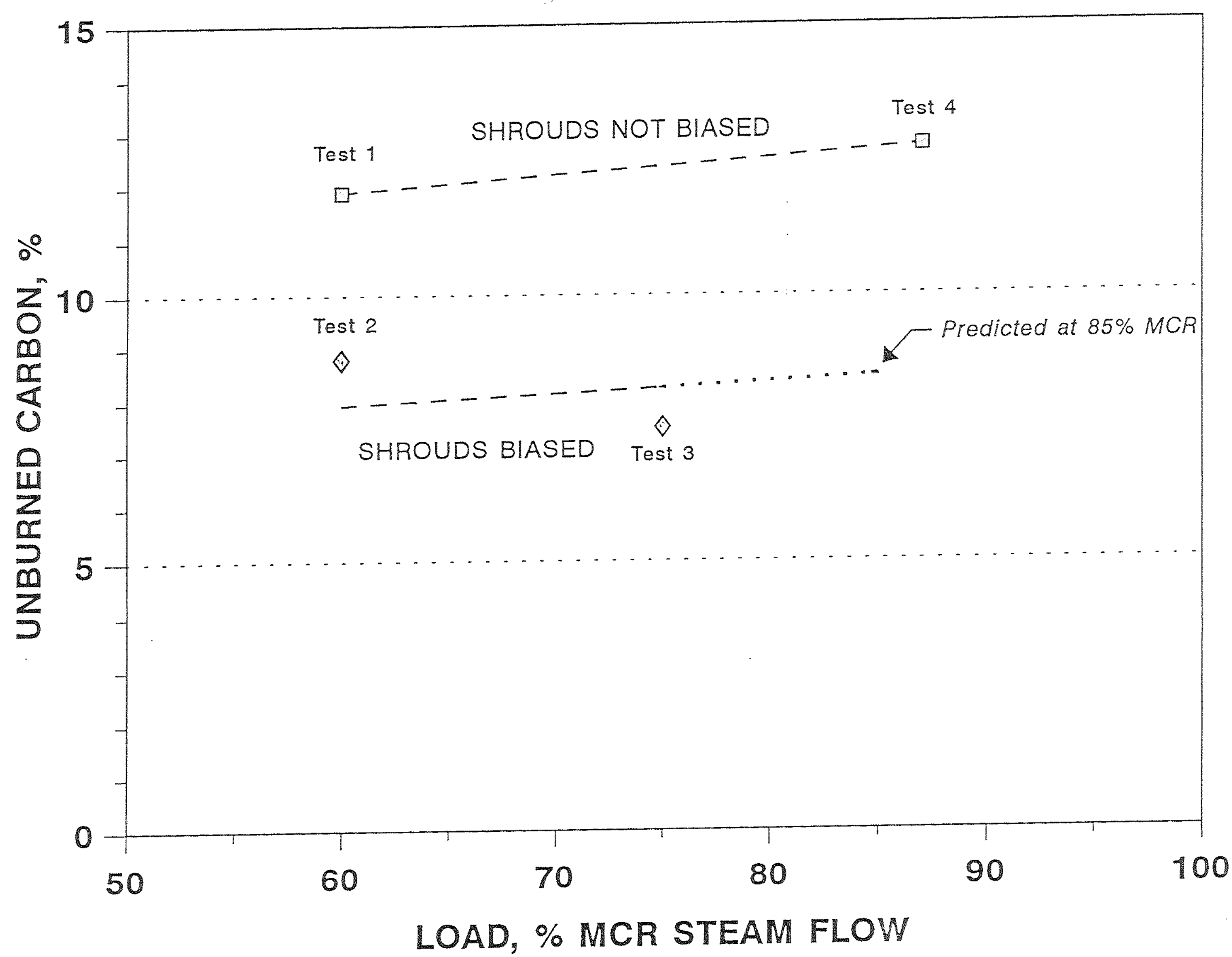


Figure 8. Flyash Unburned Carbon vs. Load