CONTROLLING NO_x EMISSIONS TO MEET THE 1990 CLEAN AIR ACT

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Craig A. Penterson
Senior Staff Engineer
Fuel Equipment Design
Riley Stoker Corporation

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ABSTRACT

Recent amendments to the Clean Air Act, requiring more stringent NO_x emission levels, have instigated a careful review, by the original equipment manufacturers, of all combustion system technologies available to meet these emissions. Riley Stoker has determined that the low NO_x burner technologies developed by Riley in the early 1980's will indeed meet the 1990 Clean Air Act emission requirements while maintaining steam generator performance under recommended operating conditions.

This paper discusses Riley Stoker's low NO_x burner technology for coal fired applications in the 1990's. Results of performance testing a low NO_x combustion system installed on a 400,000 pounds of steam per hour industrial TURBO®-Furnace and on a 805,000 pounds of steam per hour utility front wall fired unit are presented. Results clearly demonstrated the ability of these combustion systems to reduce NO_x emissions to as low as 0.3 lb/10^6 Btu with excellent carbon burnout efficiency.

Several other projects currently underway to reduce NO_x emissions from coal firing, as mandated by the 1990 Clean Air Act, are also briefly discussed.

INTRODUCTION

The 1990 Clean Air Act Amendment has limited, by 1995, NO_x emission levels for several existing pulverized coal fired installations to 0.5 lb/10^6 Btu in wall fired designs and 0.45 lb/10^6 Btu in tangential applications (1). New boiler installations will be required to limit NO_x emissions to 0.3 lb/10^6 Btu.

Riley Stoker has been developing and implementing low NO_x combustion systems for the past 20 years. Early NO_x emission control focused on reducing NO_x emissions through the use of flue gas recirculation (FGR), overfire air (OFA), burners out of service (BOOS) and low excess air (LEA) operation (2). While these methods were effective at reducing NO_x, it was usually at the expense of deteriorating boiler performance. The 1980's thus focused on developing low NO_x burners to meet the NO_x requirements without degradation in boiler performance. The Controlled Combustion Venturi (CCV^{TM}) burner was developed for wall fired boilers and the Tertiary Staged Venturi (TSV^{TM}) burner was developed for TURBO® Furnace, down fired and arch fired boilers.

Recent performance testing has shown the ability of the CCV^{TM} burner to lower NOx emissions in a wall fired utility boiler to < 0.5 lb/10^6 Btu without overfire air. The TSV^{TM} burner was capable of lowering NO_x emissions in an industrial TURBO® Furnace to < 0.3 lb/10^6 Btu when combined with an air staging system. In both cases, boiler performance, in regard to steam temperature, boiler efficiency, controllability and reliability was maintained or improved throughout the boiler load range.

DESCRIPTION OF LOW NO_x CCV^{TM} BURNER SYSTEM

The CCV^{TM} burner, shown in Figure 1, is a single register swirl stabilized low NO_x pulverized coal burner for wall fired boilers.

The key element of the burner design is the patented (U.S. Patent No. 4,479,442) Venturi coal nozzle and low swirl coal spreader located in the center of the burner. NO_x control is achieved through this design. The Venturi nozzle concentrates the fuel and air in the center of the coal nozzle creating a very fuel rich mixture. As this mixture passes over the coal spreader, the blades divide the coal stream into four (4) distinct streams which then enter the furnace in a gradual helical pattern producing very gradual mixing of the coal and secondary air. Secondary air is introduced to the furnace through the air register, supported off the burner front plate, and subsequently through the burner barrel. Devolatilization of the coal in the fuel rich mixture occurs at the burner exit in an oxygen lean primary combustion zone, resulting in lower fuel NO_x conversion. Peak flame temperature is also reduced, thus suppressing the thermal NO_x formation.

Additional NO_x reduction is achieved through external air staging or overfire air by further limiting the oxygen concentration in the primary combustion zone. In most cases, the CCV^{TM} burner alone is capable of reducing NO_x by 30-50%. When combined with an OFA system the CCV^{TM} burner can reduce NO_x emissions 50-70% from pre-NSPS levels.

The air register/shroud assembly provides independent control of swirl and secondary air flow. The swirl is controlled by a multiple bladed register assembly using an externally mounted register drive. This manually adjusted register drive is set once during start-up. A movable air shroud surrounding the register assembly automatically controls burner air flow. The burner is equipped with a pitot tube for measuring air flow for balancing secondary air burner to burner. The register and secondary air barrel are connected by an expansion joint to allow for relative movement caused by varying boiler and windbox expansion rates. Control of secondary air flow to each burner is done by moving the shroud. Air flow measurement to each burner is read by the pitot tube and transducer that feeds the air flow signal back to the control system. By moving the shroud, air flow is balanced to each burner to match the coal flow from the mills. The shrouds are also used to maintain windbox pressure (set point 3") to assure efficient combustion throughout the load range by promoting good secondary air distribution.

RESULTS OF CCV^{TM} BURNER TESTING

CCV^{TM} burners were recently installed on Public Service of Indiana's (PSI) Wabash River Unit 5 to reduce NO_x emissions. The unit is a Riley Stoker pulverized coal fired steam generator with a rated capacity of 805,000 pounds of steam per hour, at a design pressure of 2075 psig and a final steam temperature of 1000°F superheat and 1000°F reheat with an operating throttle pressure of 1850 psig. Pulverized coal is supplied by three single ended ball tube mills feeding 12 burners. At this steam flow rate, the unit produces 125 megawatts of electrical power. This unit was commissioned in 1955 and has been successfully operated over the last 35 years.

Figure 2 shows a side elevation view of the Wabash River Station.

Careful review of the pulverizer system operation and performance prior to the retrofit revealed major problems such as excessive mill plugging with limitations in boiler load due to wet coal, inadequate burner inlet primary air temperatures, insufficient coal fineness, high carbon loss, and poor fuel distribution to the burners. It was felt the new burners would effectively reduce the NO_x emissions but additional work would be required to resolve these mill system issues and to provide PSI with an overall acceptable and reliable boiler system. It was necessary for the entire pulverizer system to be upgraded. Installing new CCV^{TM} burners alone would not resolve all these issues.

The pulverizer system was, therefore, upgraded by installing new Model 80 shrouded crusher dryers, new Model 80 centrifugal classifiers, new two way coal pipe riffles, new coal pipe orifices and a new primary air bypass system.

With the new equipment installed including the low NO_x CCV^{TM} burners, the boiler operation improved dramatically. As shown in Figure 3, NO_x emissions were reduced from > 0.8 lb/10^6 Btu to < 0.5 lb/10^6 Btu which represented a 50% reduction without OFA ports. Carbon loss, measured as % loss on ignition (LOI) decreased from > 10% to < 3% while all the mill related problems were resolved. Heat rate was also reduced from 12,500 to 10,500 Btu/KW following the retrofit which represents a significant cost savings for PSI. Also included in this heat rate reduction were repairs to the boiler casing, economizer rebuild and turbine overhaul. The reduction in carbon loss contributed to this heat rate improvement but was not the only contributor.

DESCRIPTION OF LOW NO_x TSV^{TM} BURNER SYSTEM

The TSV^{TM} burner, shown on the right of Figure 4, is similar to the CCV^{TM} burner but utilizes additional tertiary air and an advanced air staging system for reducing NO_x emissions in Riley TURBO® Furnaces, down fired and arch fired boilers. The Riley TURBO®-Furnace has been used for many years as an efficient way of burning pulverized coal and a wide variety of other fossil fuels particularly the low volatile fuels (3). The inherently long furnace retention time combined with the more gradual or distributed mixing of the coal and air typically results in lower NO_x emissions than a wall-fired unit at comparable operating conditions.

An advanced air staging system integrated with the low NO_x TSV^{TM} burner is conceptually shown in Figure 4. Similar to the CCV^{TM} burner, the TSV^{TM} design features a Venturi shaped coal nozzle and low swirl coal spreader. The principals of reducing NO_x are the same as with the CCV^{TM} burner.

Surrounding the Venturi shaped coal nozzle is swirling secondary air imparted by an air register for flame stability and combustion control. Tertiary air is introduced through outboard tertiary air ports surrounding the burner proper. Directional vanes within these ports can be used to direct the tertiary air into or away from the primary combustion zone as desired. The burner zone is designed to operate with only 60-75% of total combustion air.

The remainder of the air, required to complete the combustion process and to provide additional staging for NO_x control, is added through furnace staging ports located above and below the burners. Staged combustion combined with low NO_x burners has been proven to be a very effective technology for controlling NO_x emissions.

RESULTS OF TSV^{TM} BURNER TESTING

In 1982, the low NO_x TSV^{TM} burner system was integrated into the design of a 400,000 pounds of steam per hour industrial TURBO®-Furnace. The boiler was owned and operated by a major paper manufacturer in the Midwest. It was designed to produce steam at 750°F and 630 psig operating pressure necessary to operate the paper milling equipment for manufacturing tissue paper.

Figure 5 shows a front and side elevation view of the boiler #4 installation. Six (6) TSV^{TM} burners rated at 85 x 10^6 Btu were mounted on the furnace sidewalls with overfire air (OFA) above and underfire air (UFA) below each burner. Three (3) Riley Atrita pulverizers were used to process and convey pulverized coal to the burners. An additional benefit for UFA is to provide an oxidizing atmosphere in the lower furnace to minimize waterwall corrosion.

Recently, performance tests were conducted to determine the fullest capability of this low NO_x combustion system to reduce NO_x emissions. Tests were conducted while burning a Wyoming and Oklahoma bituminous coal. Gaseous emissions were recorded at the boiler outlet while carbon burnout efficiencies were determined for selected tests. Figure 6 shows a comparison of the two (2) coals tested.

Testing began by measuring the same NO_x level that the unit was operating at six (6) years ago following boiler start-up (0.45 lbs/10^6 Btu). Various other burner settings were then evaluated with the primary emphasis on reducing burner zone stoichiometry since this effect on NO_x emissions dominates all other adjustments.

Figure 7 shows the effect of air staging on NO_x emissions at full load. Both the UFA and OFA ports were open with more staging air being introduced through the upper OFA ports. The NO_x emissions decreased from a high of 0.5 lbs/10^6 Btu to a low of 0.3 lbs/10^6 Btu for both coals. The NO_x emissions were higher for the Oklahoma coal as compared to the Wyoming coal at similar burner zone stoichiometries. This was due to the higher fuel nitrogen content for the Oklahoma coal. Lowest burner zone stoichiometries corresponding to the lowest NO_x emissions recorded were 0.86 and 0.925 for the Oklahoma and Wyoming coals respectively. This level of air staging is still considered to be "conventional" as compared to "advanced" when stoichiometries approach 0.7.

CO emissions and carbon burnout were excellent throughout the range of burner stoichiometries tested. Figure 8 shows the impact of air staging on carbon burnout and CO emissions. Flyash % LOI results averaged < 4% while CO emissions remained < 15 ppm for both coals. Coal fineness produced by the three (3) Atrita pulverizers was a standard grind of 98% passing 50 mesh and 85% passing 200 mesh. Since the CO and LOI curves tend to increase slightly with decreasing NO_x emissions or burner zone stoichiometry it would appear that in order to achieve the same degree of excellent carbon burnout during extremely low NO_x operation (< 0.3 lb/10^6 Btu) on eastern bituminous coals with relatively high % fixed carbon/% volatile matter ratios, finer coal grind will most likely be required. A product fineness of > 99% passing 50 mesh and > 85% passing 200 mesh would be recommended.

As anticipated, rotating the directional air vanes in the tertiary air ports so that the tertiary air was directed into the primary combustion zone increased NO_x emissions by approximately 60 ppm from the levels produced with the directional vanes pointing away. As shown in Figure 9, decreasing unit load from 100% to 75% MCR reduced NO_x emissions by approximately 25-50 ppm.

Overall boiler performance in regard to steam temperature, boiler efficiency, unit controllability and reliability were not adversely affected during the low NO_x operation.

CURRENT PROJECTS

The level of activity to reduce NO_x emissions in utility and industrial boilers has increased dramatically as a result of recent amendments to the Clean Air Act. The current projects at Riley Stoker for reducing NO_x emissions from pulverized coal firing with start-ups scheduled for the near future, are listed in Figure 10.

A full compliment of CCV^{TM} burners (48 total) have recently been installed at South Carolina Electric and Gas, Wateree Unit 2, initially without low NO_x Venturi coal nozzles and low swirl spreaders. New burners will be installed on Unit 1 in early 1992. The initial thrust of this project is to first improve mechanical reliability of the burner system on both units and then to reduce NO_x emissions at a later date.

CONCLUSIONS

Riley Stoker will continue to utilize the latest combustion control technology available for reducing NO_x emissions to meet the requirements of the recently amended Clean Air Act. The CCV^{TM} and TSV^{TM} burner technologies described in this paper are currently capable of meeting the required emissions without degradation in boiler performance.

CCV^{TM} burners can be used alone or in combination with an OFA system for reducing NO_x emissions on wall fired boilers. TSV^{TM} burners combined with advanced air staging are adaptable to TURBO® Furnace installations as well as down fired and arch fired boiler installations. However, caution must be exercised when evaluating retrofit NO_x control systems since the operating conditions of the pulverizer system may have a significant impact on the low NO_x burner performance. A total systems analysis is required in order to ensure low emissions with acceptable boiler performance.

REFERENCES

(1) Amendments to the Clean Air Act, November 15, 1990.

(2) A. Rawdon, S. Johnson, "Control of NO_x Emissions from Power Boilers," Presented at the Annual Meeting of the Institute of Fuel, Adelaide, Australia, November 1974.

(3) C. Penterson, D. Itse, "NO_x Control Technology for Industrial Combustion Systems," Presented to AFRC Symposium on Combustion Diagnostics from Fuel Bunker to Stack, October, 1983.

(4) R. Lisauskas, A. Rawdon, F. Zone, "Design and Operation of Coal Fired TURBO Furnaces for NO_x Control," Presented at the Second EPRI NO_x Control Technology Seminar, Denver, Colorado, November 1978.

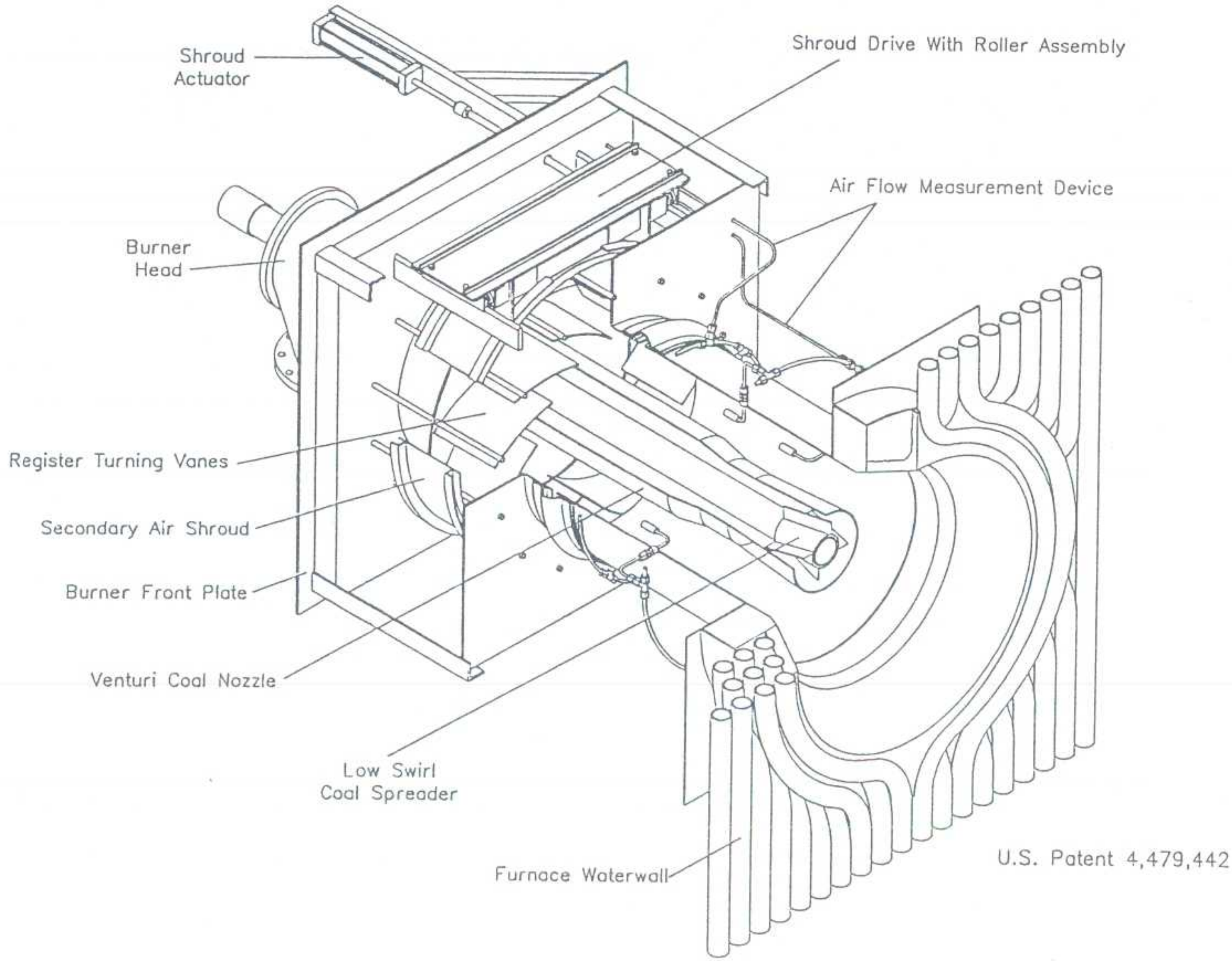


Figure 1. Riley Low NO_x Controlled Combustion Venturi (CCV) Burner for Wall Fired Boilers

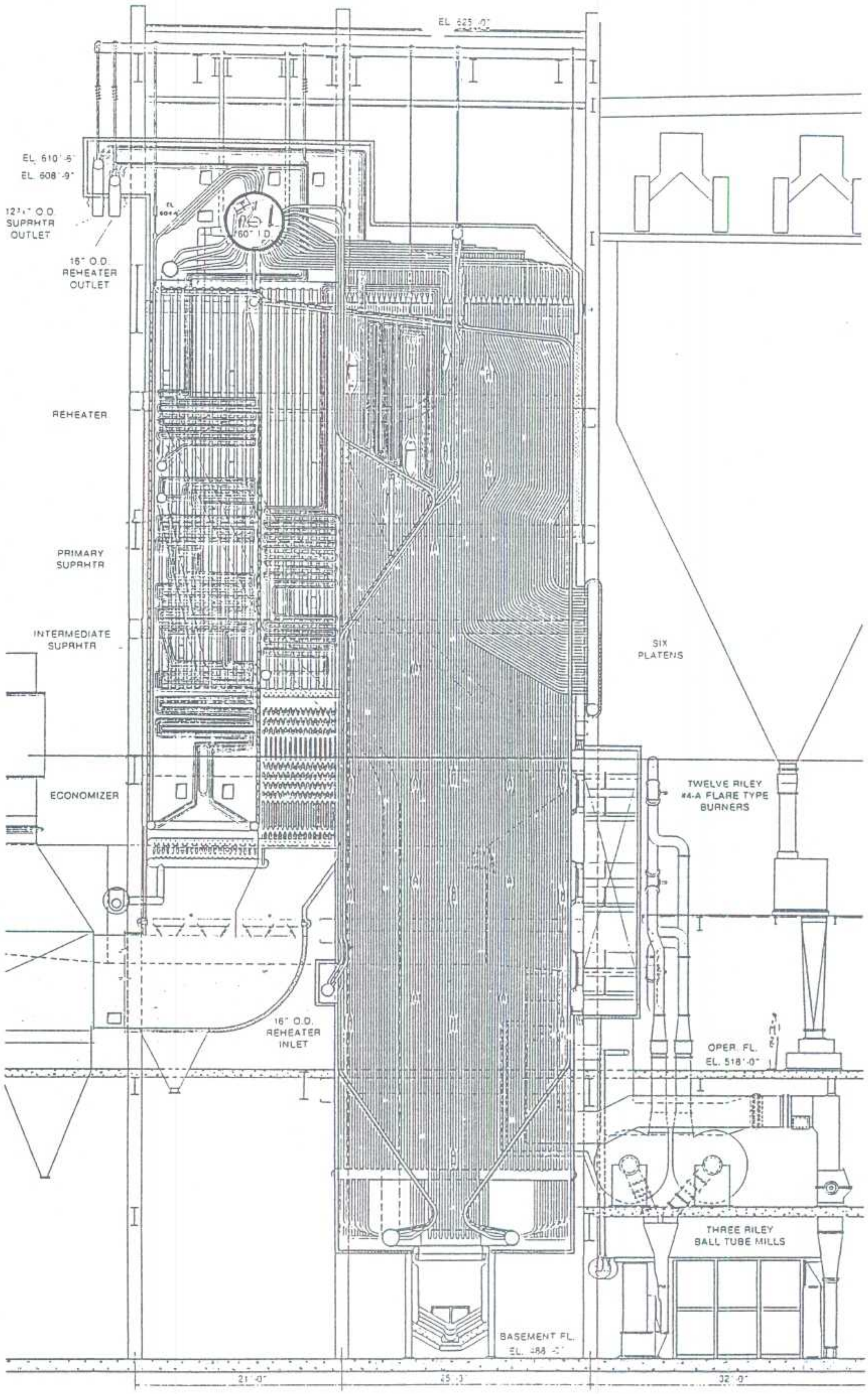
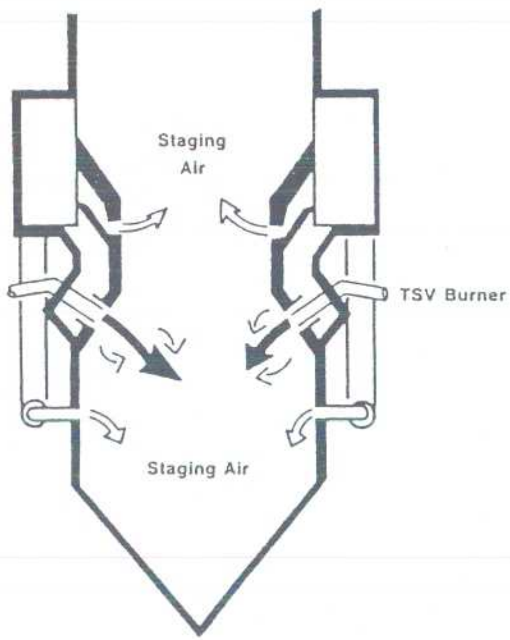


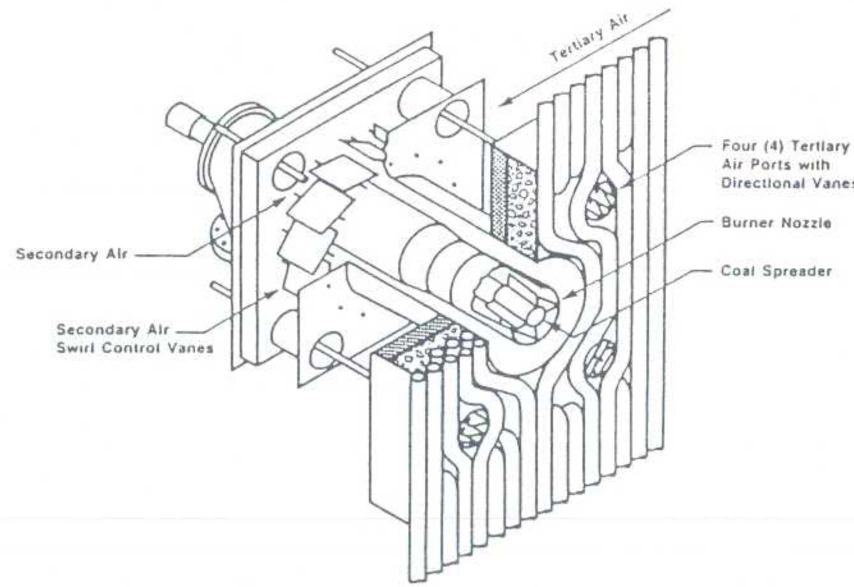
Figure 2. Wabash River Station

	BEFORE	AFTER	
• Load	65 to 105 MW	95 MW	No load reduction for wet coal
• Carbon loss	>10%	3 1/2% Ave.	Reduction of 300%
• Mill discharge temp.	≤ 107 °F	137 °F	With 18% moisture coal
• NO_x	.8 to .9 lb/10^6 Btu	.4 to .5 lb/10^6 Btu	50% reduction burners only
• Pulverized coal fineness	≤ 98%/50 ≤ 84%/200	99.8%/50 84%/200	
• Operability	Poor	Good	No load reduction for wet coal
• Windbox pressure	≤ 1" H_2O	3" H_2O	Controlled with burner shroud over load range
• Heat rate reduction		2000 Btu/kw	Significant cost savings

Figure 3. Mill System Upgrade and Low NO_x CCV Burner Results - PSI Wabash Unit 5



Advanced TURBO Furnace Staging System



TSV Burner

Figure 4. Riley Low NO_x TSV Burner with Advanced Air Staging for Turbo-Furnace, Down Fired and Arch Fired Installation

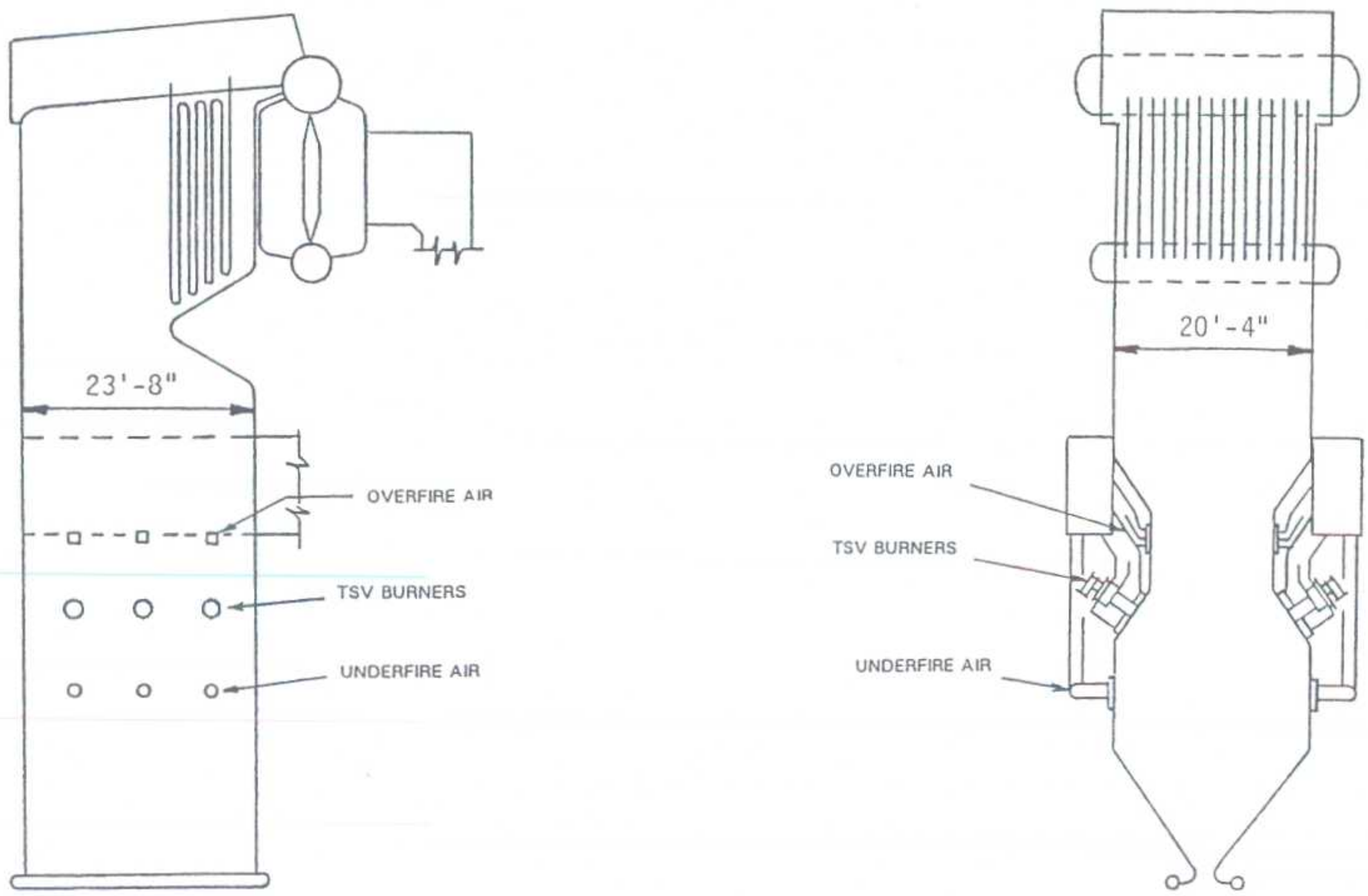


Figure 5. Cross Section of Industrial
Turbo-Furnace
Steam Capacity - 400,000 pph

	OKLAHOMA	WYOMING
Proximate (as rec'd)		
Moisture, %	15.2	12.3
Volatile Matter, %	36.6	35.6
Fixed Carbon, %	43.3	38.7
Ash, %	4.9	13.4
Ultimate (dry)		
Carbon, %	73.5	66.0
Hydrogen, %	5.3	4.9
Nitrogen, %	1.68	1.47
Oxygen, %	13.14	11.69
Sulfur, %	0.60	0.61
Ash, %	5.8	15.3
HHV, Btu/lb (dry)	12,965	11,555
Ash Fusion Temp. (H = 1/2 w)	2,250	2,220

Figure 6. Fuel Analysis Comparison - Industrial Turbo Furnace Testing

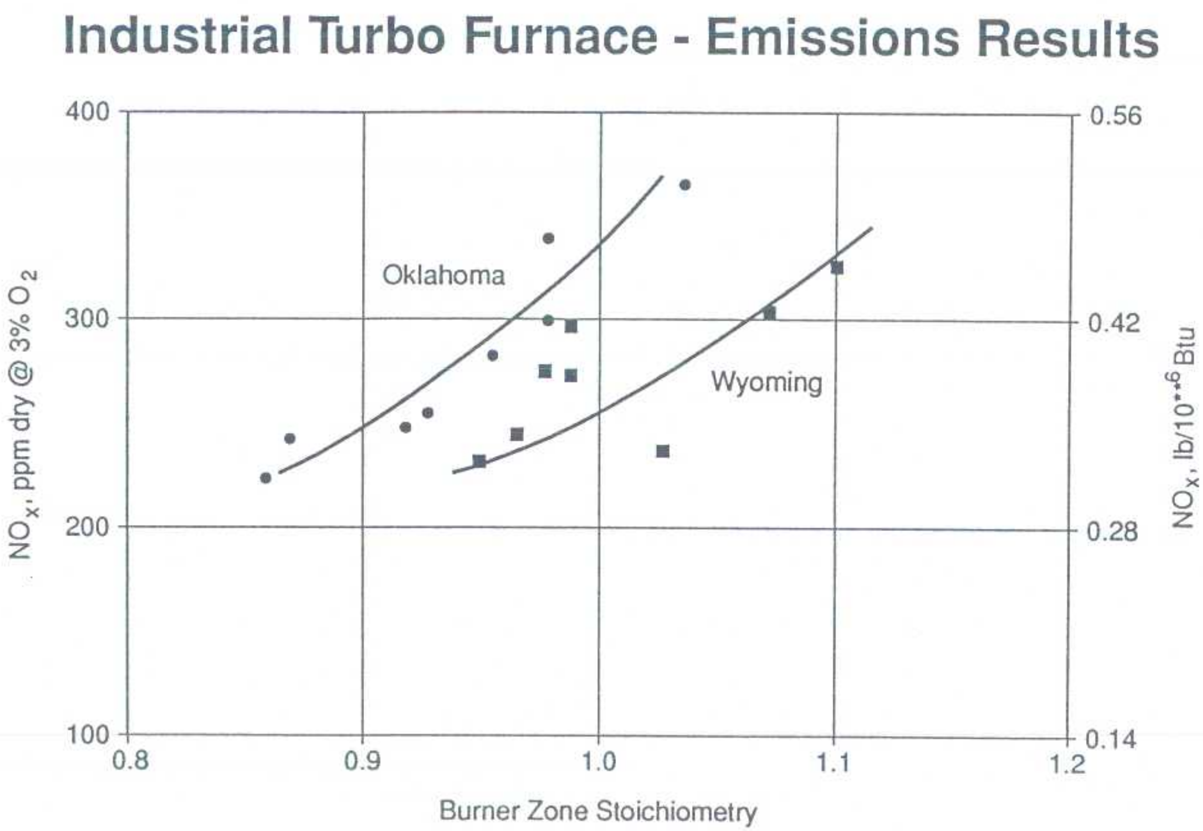


Figure 7. The Effect of Air Staging on NO_x Emissions

Industrial Turbo Furnace - Emissions Results

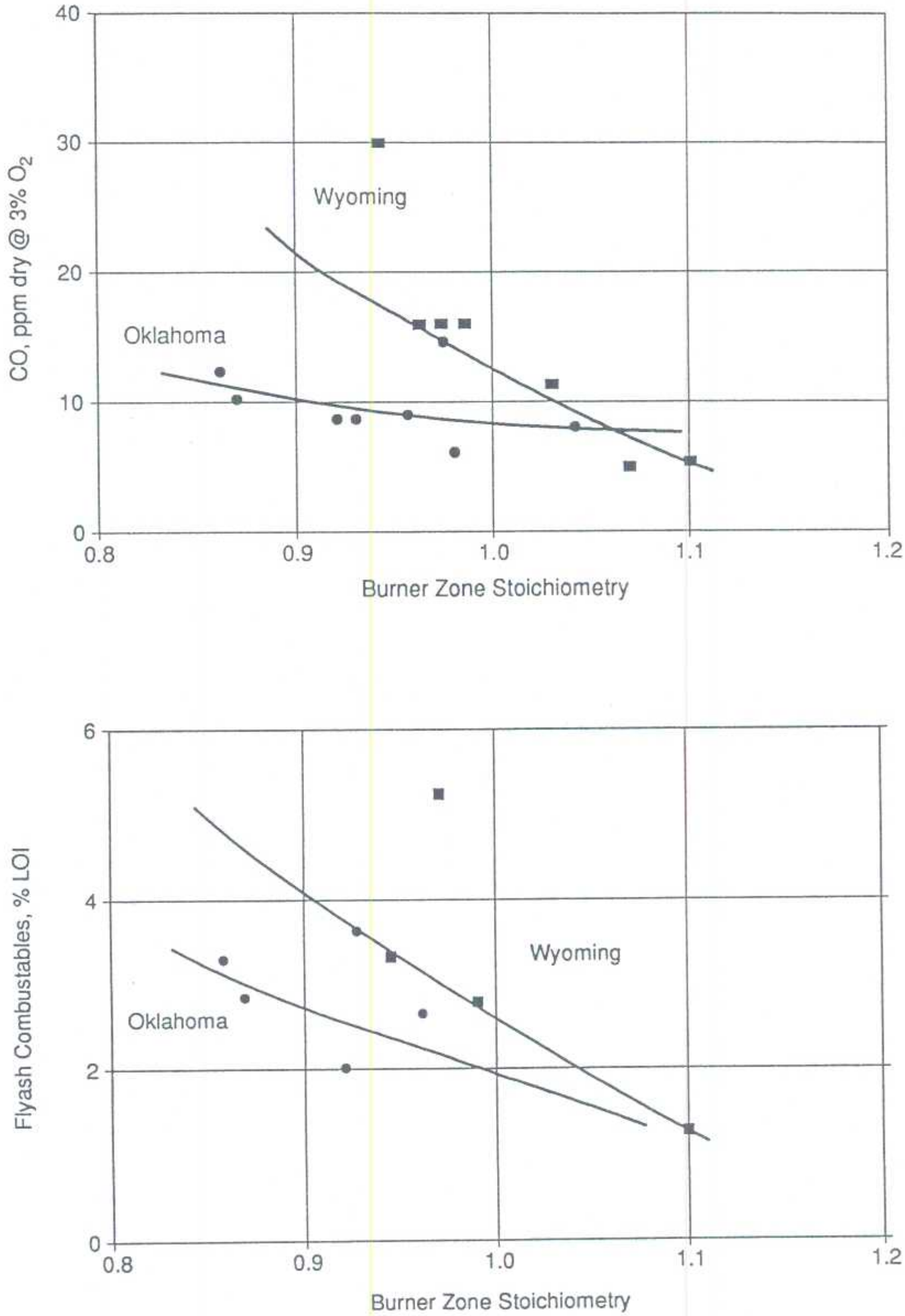
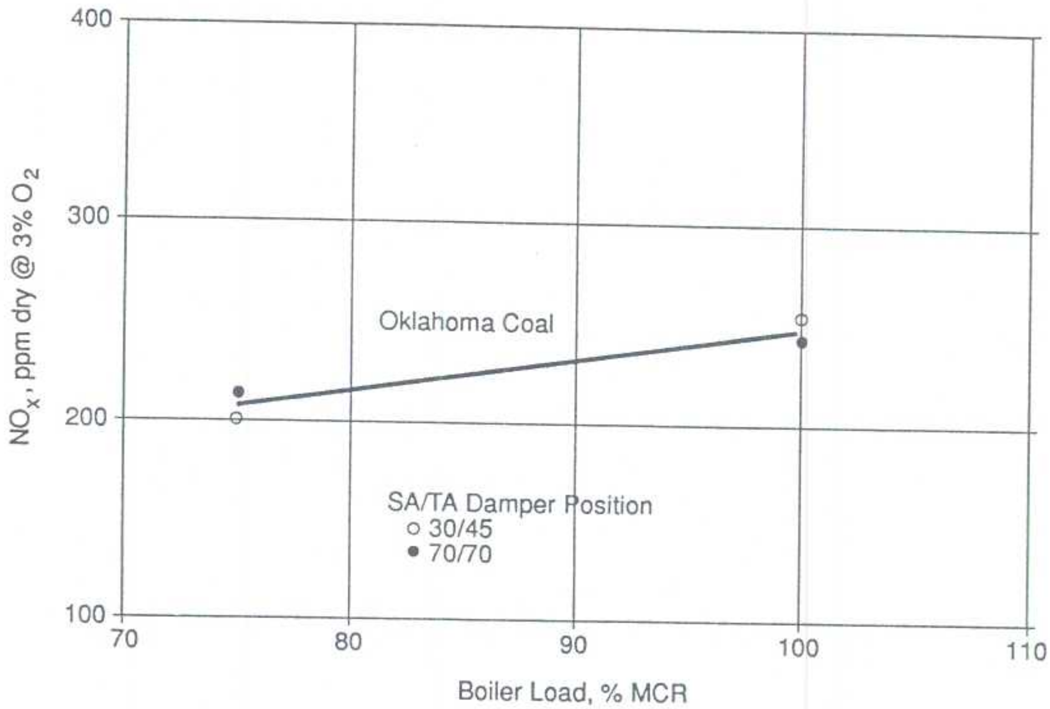


Figure 8. The Effect of Air Staging on CO Emissions and Carbon Burnout

Industrial Turbo Furnace - Emissions Results



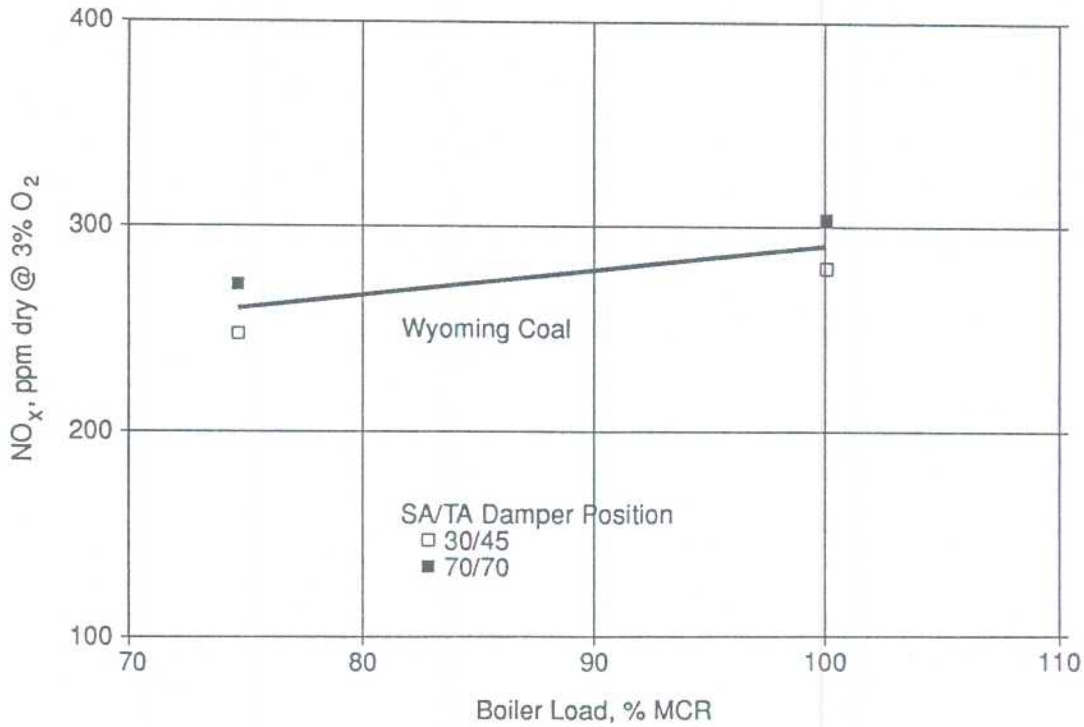


Figure 9. The Effect of Boiler Load on NO_x Emissions at Comparable Burner Settings

Customer	OEM	Steam Flow lb/hr	Burners		Fuels	NO_x Required lb/10^6 Btu
			No.	Type		
Taiwan Power Linkou Unit 1	Riley	2,100,000	18	CCV	Australian Bituminous, Oil	0.50
Public Service of Indiana Wabash Unit 2	Foster Wheeler	700,000	12	CCV	E. Bituminous	0.45
Long Chen Paper Erlin, Taiwan	Riley/Mitsui	286,000	4	TSV	Indonesian Bituminous, Oil	0.50
Allegheny Power Albright Station Unit 1	Riley	700,000	12	CCV	E. Bituminous	0.60(1)
Westmoreland Hadsen/Ultrasystems Roanoke Valley	Riley	1,250,000	16	CCV	E. Bituminous	0.33
Tennessee Eastman Co. Boiler No. 31	Riley	600,000	12	CCV	E. Bituminous	0.30

(1) Predicted NO_x Emissions < 0.5 lb/10^6 Btu

Figure 10. Current NO_x Reduction Projects at Riley Stoker for Coal Fired Installations