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COMBUSTION CONTROL OF NO_x EMISSIONS FROM COAL FIRED UTILITY BOILERS

by

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ABSTRACT

Riley Stoker has been utilizing the low NO_x Controlled Combustion Venturi (CCV) burner for controlling NOx emissions from utility and industrial boilers, both new and retrofit, since the early 1980s. Experience to date has demonstrated 50-70% NOx reduction from pre-NSPS levels with acceptable boiler performance.

However, increasingly stringent NOx regulations has created a strong need for the original equipment manufacturers to continue developing more advanced combustion systems technology to avoid the relatively high cost and uncertainty of post combustion NO_x control techniques.

This paper discusses the technology that Riley Stoker uses to control NO_x emissions from utility boilers to levels approaching 0.3 lb/10^6 Btu. Results of recently retrofitting Riley CCV" burners on utility boilers are presented The data presented includes emissions as well as the effects of low NO_x systems on boiler performance.

Pilot scale results of testing a 100 x 10^6 Btu/hr CCV^W burner incorporating new advanced design concepts on several different eastern bituminous coals in Riley Stoker's combustion test furnace are presented. Results demonstrated excellent combustion performance over a wide range of coals having volatile matter contents of 18-40%, and fuel nitrogen contents of 1.4-1.8%.

INTRODUCTION

Even though Riley has been utilizing the low NO_x CCV' burner for new and retrofit utility boilers since 1980 (1), much of the activity involving increased NO_x control has occurred in recent years. Implementation of the 1990 Clean Air Act by Congress has instigated numerous retrofit projects for reducing NO_x emissions 50% or greater. The presumed NO_x emission limit for wall fired utility boilers from now to 1995, is < 0.5 lb/10^6 Btu (2). State and local levels are even less. CCV™ burner performance from utility boilers has demonstrated NO_x levels < 0.4 lb/10^6 Btu without adversely impacting overall boiler performance (3).

Recent pilot testing in Riley's 100 million Btu/hr combustion test furnace has resulted in design enhancements for achieving low emission levels without the use of air staging or overfire air ports. In addition, testing a number of different eastern bituminous coals has shown the CCV™ burner will perform satisfactorily over a wide range of fuel properties.

DESCRIPTION OF LOW NO_X CCV™ BURNER SYSTEM

The CCV™ 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.

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 a metal 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. Relative air flow measurement to each burner is read by the pitot tube and locally mounted magnahelic pressure gage.

The shrouds are used to automatically control a pre-selected windbox pressure throughout the boiler load range. By partially closing the shrouds, this windbox pressure will increase to the level necessary for proper OFA flow rates, penetration velocity and good burner air distribution. A typical windbox pressure control range may vary from 4" at full 100% load to 1.5" at 50% load. Maintaining a constant windbox pressure throughout the load range is not necessary. No additional ducting or dampers are required for this function.

In most cases the CCV™ burner alone has been capable of reducing NO_x by 30-50%. When combined with an OFA system, the reduction amounts increase to 50-70% from uncontrolled pre-NSPS levels.

This level of NO_x reduction has been achieved utilizing the Riley CCV™ burner equipped with only one (1) secondary air register which results in a mechanically simple design. Several years ago during the early development stages of the CCV burner, Riley evaluated and tested dual register designs. We found <u>no</u> advantage in using dual registers for the present NO_x emission levels being required. The fact that the Riley design does not utilize "core air" in the center of the burner may contribute to this capability.

FIELD EXPERIENCE

Since 1990, Riley has proposed and sold many utility customers low NO_x combustion systems technology utilizing our patented CCV burner with and without OFA. As shown in **Table 1**, the list includes new and retrofit applications on Riley boilers as well as other OEM boilers. Within the next two (2) years, Riley will have over 3000 MW of installed capacity and over 250 burners in operation.

Results of recently retrofitting Riley low NO_x combustion systems on a few utility boilers are discussed below:

Taiwan Power Company Linkou Unit 1

This boiler is a Riley Stoker front wall fired steam generator with a maximum continuous rating (MCR) of 2,100,000 lb/hr main steam flow at 1008°F/1008°F superheat and reheat steam temperature and 2525 psig operating pressure. The furnace dimensions are 46' W x 36' D. Pulverized coal is supplied by 3 double ended ball tube mills which feed eighteen (18) burners arranged in three (3) rows of six (6) burners per row. The turbine is rated to generate 300 MW of electricity. The unit was commissioned in 1965 and has been successfully operated over the last 25 years.

In the spring of this year, the unit was retrofitted with a new Riley low NO_x combustion system for purposes of reducing the NO_x emissions from an uncontrolled level of 1.04 $lb/10^6$ Btu to < 0.5 $lb/10^6$ Btu with future requirements of < 0.45 $lb/10^6$ Btu. The new low NO_x system Riley installed included eighteen (18) low NO_x CCV™ burners each rated for 155 million Btu/hr, and an advanced overfire air system. As shown in **Figure 2**, the overfire air system consisted of a separate header duct feeding eight (8) OFA ports on the front wall and four (4) OFA ports on both sidewalls. Typically, OFA ports are only installed on the burner wall. However, in this application, they were also installed along the sidewalls since we felt the residence time available for burnout from the OFA port elevation to the furnace exit was relatively short. From flow model studies performed by Riley Research for EPRI in the mid 1980s (4), we learned that this type of arrangement produces better mixing in the same time duration than only having front wall OFA ports installed. Ideally, the best arrangement is with ports on all four (4) walls. The 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. In other words, 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.

Combined with this OFA system was installed a boundary air system which introduced a small portion of combustion air along both sidewalls near the hopper bend line. The purpose of this air was to maintain a localized oxidizing atmosphere adjacent to the sidewalls to minimize potential tube corrosion as a result of operating the lower furnace sub-stoichiometrically for controlling NO_x.

During the design phase of this retrofit project, a 1/12th scale plexiglas flow model was constructed and tested at Riley's R & D facility. The purpose was to evaluate the air distribution to all the burners and OFA ports and develop internal vaning or modifications as necessary to ensure acceptable distribution. Results of the testing showed the burner and OFA flow distributions were within acceptable limits without the need for internal guide vanes. The proper location for the OFA/combustion air partition plate was determined. The information learned in this model study has been used to develop OFA system designs on other boiler applications.

Two (2) baseline tests were performed on Linkou Unit 1 prior to the low NO_x retrofit to determine the uncontrolled emission levels and to quantify boiler performance. Data recorded in February 1988, indicated the NO_x level was 1.04 $lb/10^6$ Btu while subsequent testing in July 1991, indicated the uncontrolled NO_x

level was 0.90 lb/10^6 Btu. However, as indicated by high CO emissions, poor carbon burnout and poor coal fineness, the lower NO_x level measured last year was most likely due to simply poor combustion performance and not indicative of good operation.

Tests were then conducted last August to evaluate performance of the new low NO_x combustion system Riley installed last spring. Results are summarized in **Table 2**. The NO_x emissions decreased for 1.04 to an average 0.39 lb/10^6 Btu for a 62% reduction when OFA was fully open. The boiler load tested at was 93% of MCR conditions because of limitations with ID fan capacity as a result of "dirty" air heaters. However, as discussed later, the NO_x emissions would not have been any higher at the full 100% MCR condition based on the NO_x data collected as a function of boiler load. CO emissions remained low (< 75 ppm) during the testing while % loss on ignition (LOI) remained essentially unchanged. This finding was particularly significant since, as shown in **Table 2**, coal fineness was below standard grind and the coal distribution to the burners was only ± 25% of the average coal flow.

Boiler efficiency was not effected by the new low NO_x system. The fuel burned during the testing was an eastern bituminous coal from Tennessee. **Table 3** summarizes the fuel analysis for this coal.

Figure 3 shows the effect of air staging on NO_x emissions. The OFA flow is expressed as % of total combustion air as measured by FCI flow transmitters in the OFA duct sections on both sides of the unit. The curve shows a steady decrease in NO_x with increasing amounts of OFA as expected. The NO_x level measured with OFA closed was 0.65 lb/10^6 Btu. Based on results of previously testing the CCV burner in our combustion test furnace, lower NO_x values could have been produced with OFA closed if operations would have allowed us to replace the coal spreaders with lower swirl coal spreaders. Power demand requirements during this past summer precluded our efforts to test this condition. However, NO_x emissions were predicted to be < 0.5 lb/10^6 Btu with burners only.

Figure 4 shows how the NO_x emissions remain relatively constant with a decrease in boiler load by steadily decreasing the amount of OFA flow. If the OFA remained wide open, NO_x emissions would have decreased significantly. TPC Linkou Unit 1 did not experience any furnace waterwall flame impingement before or after the low NO_x burner retrofit.

A tremendous benefit observed with the burner air shrouds during the testing was the ability to bias the burner air flow from side to side on the unit. The testing was performed during a period when one (1) air heater was considerably more dirty than the other and normal soot blowing practice would not effectively clean it. The air heater pressure drop on the dirty side was twice the pressure drop on the other resulting in a significant O_2 imbalance side to side, as measured at the economizer outlet. The burner shrouds were consequently adjusted to equalize this O_2 imbalance. Final shroud positions established on a column basis were 35%, 24%, 16%, 16%, 18% and 30% open. By biasing the shrouds such as this, the O_2 measured at the economizer outlet became balanced, CO emissions were low and superheater tube metal temperatures were more uniform across the unit.

Public Service of Indiana Wabash River Unit 5

CCV™ burners were installed in the spring of 1991 on Public Service of Indiana's 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 pph steam flow, at a design pressure of 2075 psig and final steam temperature of 1000°F superheat and 1000°F reheat.

Pulverized coal is supplied by three single ended ball tube mills feeding 12 burners. The unit, shown in **Figure 5**, generates 125 MW of electrical power. Furnace dimensions are 40'-6" wide x 23'-5" deep.

The low NO_x system retrofit included low NO_x CCV™ burners and upgrades to the ball tube mill system. The mill upgrades were the result of problems being experienced by PSI with mill plugging due to wet coal, inadequate burner inlet primary air temperatures, insufficient coal fineness, high carbon loss and poor fuel distribution to the burners. Simply replacing the existing burners with new low NO_x CCV™ burners CCV™ would not resolve all of these issues. OFA was not included in this retrofit.

With the new equipment installed including the low NO_x CCV™ burners, the boiler operation improved dramatically. As shown in **Table 4**, NO_x emissions were reduced from 0.8-0.9 lb/10^6 Btu to 0.4-0.5 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. Improvements in the coal fineness as well as the installation of more efficient pulverized coal burners, contributed to the better LOI.

City of Vineland Howard Down Unit 10

CCV™ burners and an OFA system were retrofitted to a small 17'-6" W x 19'-0" D utility boiler in the fall of 1991 owned and operated by the City of Vineland to reduce NO_x emissions. This Erie City boiler burns eastern bituminous coal from Kentucky, produces 290,000 pph steam flow and generates 25 MW of electrical power. The design pressure is 965 psig with a final superheater outlet temperature of 900°F. Pulverized coal is supplied by two (2) CE Raymond mills feeding four (4) burners.

Figure 6 shows a schematic drawing of the low NO_x combustion system equipment Riley installed to replace the original CE-RO burners. Four (4) CCV™ burners rated at 90 million Btu/hr and five (5) OFA ports were installed on the unit. Preliminary testing was performed in December, 1991 while collecting emissions data at the economizer outlet. As shown in **Table 5**, NO_x emissions decreased from 1.06 lb/10^6 Btu to .51 lb/10^6 Btu, with OFA ports closed, and .36 lb/10^6 Btu, with OFA open or > 65% reduction. CO emissions remained unchanged at < 30 ppm while the % LOI in the flyash decreased significantly from 25% to < 10%.

PILOT TESTING EXPERIENCE

A prototype CCV™ burner was installed and tested last spring in the Riley Coal Burner Test Facility (CBTF). The Riley CBTF, located in Worcester, Massachusetts and shown in **Figure 7** is a horizontal tunnel furnace with the burner mounted on one end and the exhaust exiting the other end. The furnace has a nominal firing capacity of 100 million Btu/hr on coal. The firing chamber is approximately 18' wide and 60' long. The straight vertical side walls extend 18' above the furnace hopper. The test furnace is designed to simulate flame zone temperatures in actual utility boilers. Insulating refractory covers the interior walls of the furnace up to 40' from the firing wall. A water jacket, which surrounds the steel vessel, provides cooling.

Furnace ports located on the sidewalls are used to simulate overfire air at various furnace residence times. Gaseous emissions are continuously measured at the furnace exit.

The primary purpose of the testing was to develop design enhancements for the CCV™ burner to achieve greater NO_x reduction without the need for OFA. The other purpose was to evaluate the effect of various fuel characteristics on emissions performance. A total of four (4) different eastern bituminous coals were evaluated during the test program. As shown in **Table 6**, the volatile content ranged from 18.9% for Coal D to 35.7% for Coal B. The resulting fuel factor or fixed carbon/volatile matter ratio ranged from 1.42 to 3.51. Combined with this data was data collected in 1988 from testing the CCV™ burner on two (2) additional coals having FC/VM ratios of 1.17 and 1.87 (6).

The prototype burner was designed with a special coal spreader where the blade angle could be adjusted on line for test purposes. For commercial operation, this coal spreader would remain as a "fixed" design. The design enhancement added to the prototype burner was the inclusion of a secondary air diverter mounted adjacent to the discharge end of the coal nozzle. **Figure 8** shows a drawing of the prototype burner design with the new secondary air diverter.

The secondary air diverter causes more secondary air to initially flow away from the primary combustion zone, thus expanding the reducing zone at the burner discharge. This promotes greater devolatilization of the coal in this reducing environment which contributes to greater NO_x reduction. Recirculation eddies created on the backside of the diverter also helps to intensify ignition of the coal and helps to promote the devolatilization process. Based on laboratory testing, the diverter maintains a well attached flame with good ignition close to the coal nozzle tip for a wide variation in coal spreader designs. This flexibility allows for better NO_x control over a wide range of operating conditions and coal properties.

Figure 9 shows the effect of adjusting the coal spreader angle on NO_x emissions comparing the original CCV™ burner design (CCV™ 88) with the prototype design, having the new secondary air diverter (CCV™ 92). The data, collected during unstaged operation (OFA ports closed), shows a significant improvement in NO_x performance for the CCV™ 92 at spreader angles from 30° maximum down to 15°. Below 15°, both burner designs behaved similarly. A data point representing the level of NO_x measured in the CBTF from Riley's pre-NSPS high turbulence flare type burner is also shown for comparison. The testing showed the capability of the CCV™ burner design (Model 92) to reduce NO_x emissions > 60% without the requirement for OFA ports.

Figure 10 shows the effect of air staging, on NO_x emissions. Similar to the previous figure, the data compares CCV™ 88 and CCV™ 92 low NO_x burner designs with the original flare type burner. The CCV™ 92 burner design was capable of producing NO_x emissions below 0.27 lb/10^6 Btu when staged to 0.9 burner zone stoichiometry. An important discovery though was that the NO_x performance measured from the CCV™ 92 burner design was less sensitive to the degree of staging than the previous burner designs.

Figure 11 shows the effect of variations in fuel factor or FC/VM ratio on NO_x and CO emissions performance. The data was collected while testing the CCV™ 92 burner design with adjustable coal spreader blades set at 15° with respect to the burner axis. Contrary to what we anticipated, the NO_x performance was insensitive to this fuel property variation. Previous investigators had found that NO_x emissions increase with an increase in FC/VM ratio (7). If anything, the data collected on the CCV™ 92, showed a decrease in NO_x with an increase in FC/VM ratio during staged operation. For unstaged operation, the NO_x curve was relatively flat.

A more significant effect of the fuel factor was the impact on CO emissions. This was consistent with what was expected. CO emissions increased 50% with an increase in FC/VM ratio from 1.4 to 2.0. CO emissions then increased at only a moderate rate up to FC/VM = 3.51. Flyash LOI increased similarly. The CO emissions were slightly higher for staged operation.

SUMMARY

Riley Stoker has successfully retrofitted the Controlled Combustion Venturi burner on several coal fired utility boilers. The retrofits have involved installing CCV™ burners alone or in combination with advanced and conventional overfire air systems. NO_x emission levels below 0.38 lb/10^6 Btu have been demonstrated on retrofit applications without deterioration in boiler performance. In some cases, combustion efficiency has actually improved.

The latest CCV™ burner design enhancement incorporating the secondary air diverter has improved NO_x reduction performance 25-30%. NO_x emission levels below 0.35 lb/10^6 Btu were measured in the Riley Coal Burner Test Facility unstaged or without the use of overfire air. NO_x levels well below 0.30lb/10^6 Btu were recorded when combining the CCV™ burner with overfire air. This performance was also maintained over a wide range of coal properties. Further analysis to determine correlations with other fuel characteristics is currently being performed.

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Table 1 Riley Low NO_x CCV Burner Experience List Since 1990							
Unit	**MW**	**Year**	**OEM**	**# Burners**	**NO_x ($lb/10^6$ Btu)**		
					Before	**After**	**% Reduction**
A	125	1990	Riley	12	0.99	0.50	50
B	25	1991	Erie City	4	1.06	0.36	66
C	385	1991	Riley	24	1.10	-	-
D	385	1992	Riley	24	1.10	-	-
E	100	1992	FW	12	0.80	-	-
F	300	1992	Riley	18	1.04	0.38	63
G	80	1993	Riley	12	0.94	-	-
H	180*	1993	Riley	16	-	-	-
I	75*	1993	Riley	12	-	-	-
J	150	1993	Riley	18	-	-	-
K	80	1993	Riley	12	0.94	-	-
L	375	1993	B & W	24	1.35	-	-
M	100	1994	Riley	16	0.80	-	-
N	265	1994	B & W	24	1.10	-	-
O	375	1994	B & W	24	1.35	-	-
P	165	1994	Riley	16	0.96	-	-
Total	3165 MW			268 Burners			

*New Boiler

Table 2
Taiwan Power Company Linkou Unit 1
Emissions Test Results

Test Type	Baseline	Baseline	Post Retrofit	Post Retrofit
Date	2/88	7/91	8/92	8/92
Burner Design	Flare	Flare	CCV	CCV
OFA, %	0	0	24	26
NO_x, lb/10^6 Btu	1.04	0.90	0.43	0.38
CO, PPM	20	300	50	70
Flyash LOI, %	-	8.5	8.2	-
Bottom Ash LOI, %	-	-	3.3	-
Coal Fineness % - 50 Mesh % - 200 Mesh	 96.9 67.8	 94.0 64.3	 95.5 66.1	 95.5 66.1

Table 3
Taiwan Power Company
Linkou Unit 1 Fuel Analysis

H_2O (%)	5.00
VM (%)	35.10
FC (%)	49.40
Ash (%)	10.50
C (% dry)	73.40
H (% dry)	5.00
O (% dry)	8.14
N (% dry)	1.46
S (% dry)	0.90
HHV (Btu/lb)	12,418

Table 4 **Mill System Upgrade and Low NO_x CCV Burner Results - PSI Wabash Unit 5**			
	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 ≤ 74%/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

Table 5 **City of Vineland Howard Down Unit 10** **Emissions Test Results**			
Test Time	Baseline	Post Retrofit	Post Retrofit
Date	12/89	12/91	12/91
Burner Design	CE-RO	Riley - CCV	Riley - CCV
OFA	-	Closed	Open
NO_x, lb/10^6 Btu	1.06	0.51	0.36
CO, PPM	25	24	27
Flyash LOI, %	25	8.7	11.3(1)

(1) Subsequent testing in January, 1992 resulted in 4.9% LOI with OFA open.

Table 6 CBTF Pilot Tests Range of Coals Tested				
	A	B	C	D
H_2O (%)	7.6	4.6	1.9	5.2
VM (%)	29.8	35.7	25.9	18.9
FC (%)	57.9	50.7	53.2	66.3
Ash (%)	4.7	9.0	19.0	9.6
C (% dry)	83.8	75.1	68.9	80.0
H (% dry)	5.1	5.1	4.4	4.4
O (% dry)	3.9	7.5	4.7	2.7
N (% dry)	1.4	1.5	1.3	1.4
S (% dry)	0.7	1.5	1.5	1.4
HHV (Btu/lb)	13731	12867	11989	13306
FC/VM, -	1.94	1.42	2.05	3.51

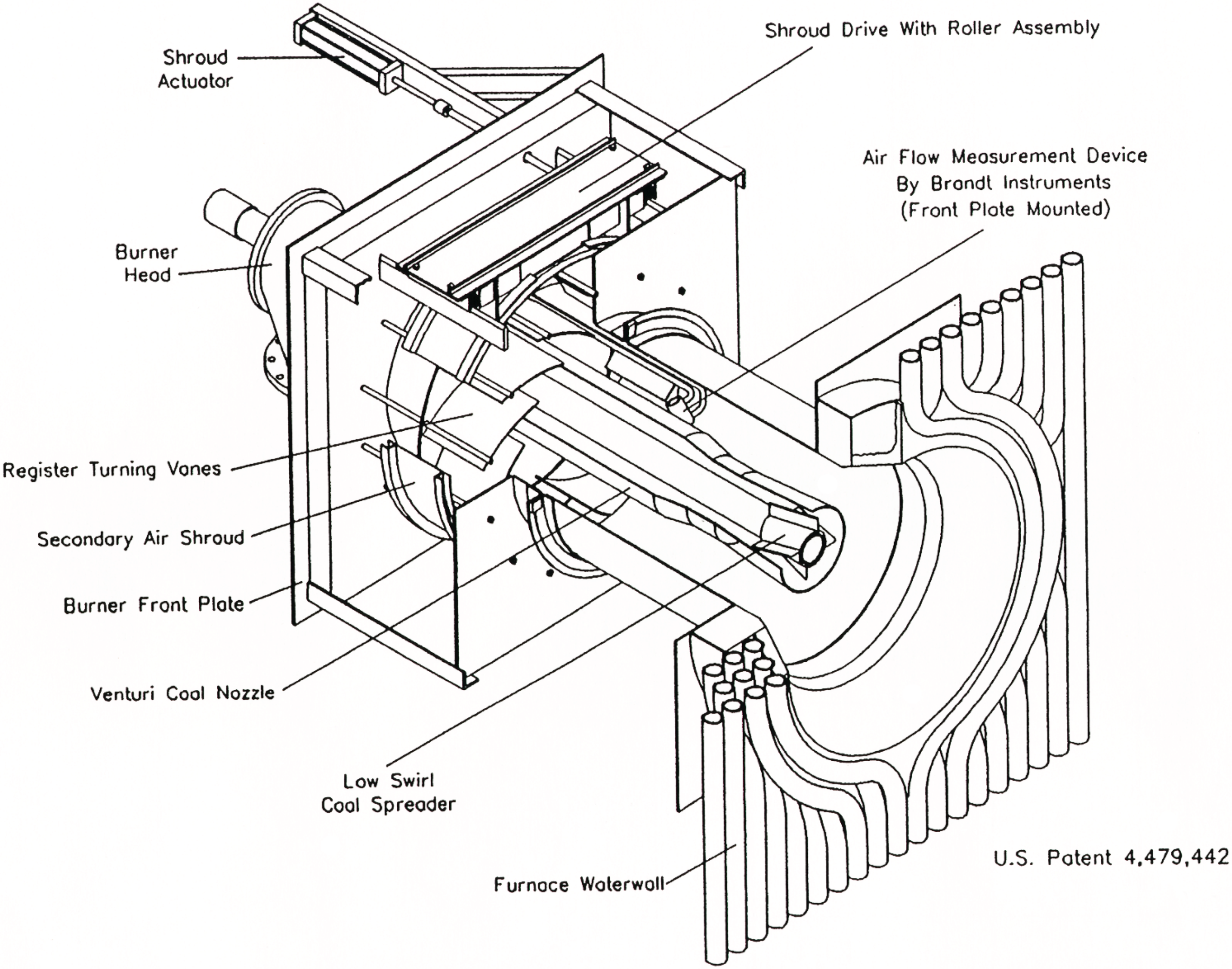

Figure 1. Riley Low NO_x Controlled Combustion Venturi (CCV™) Burner

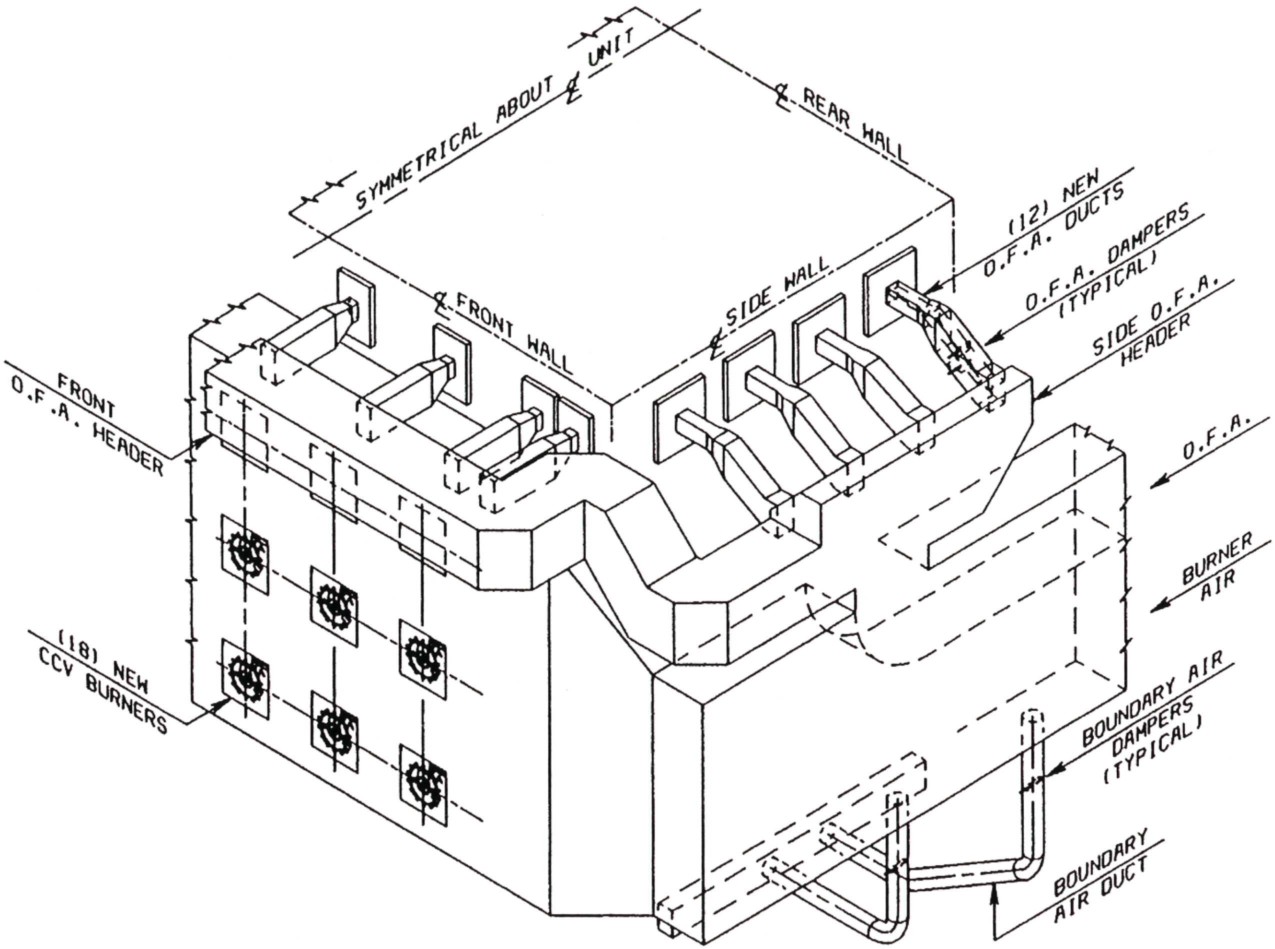

Figure 2. Low NO_x Combustion System Retrofit for Taiwan Power Company Linkou Unit 1 300 MW Boiler

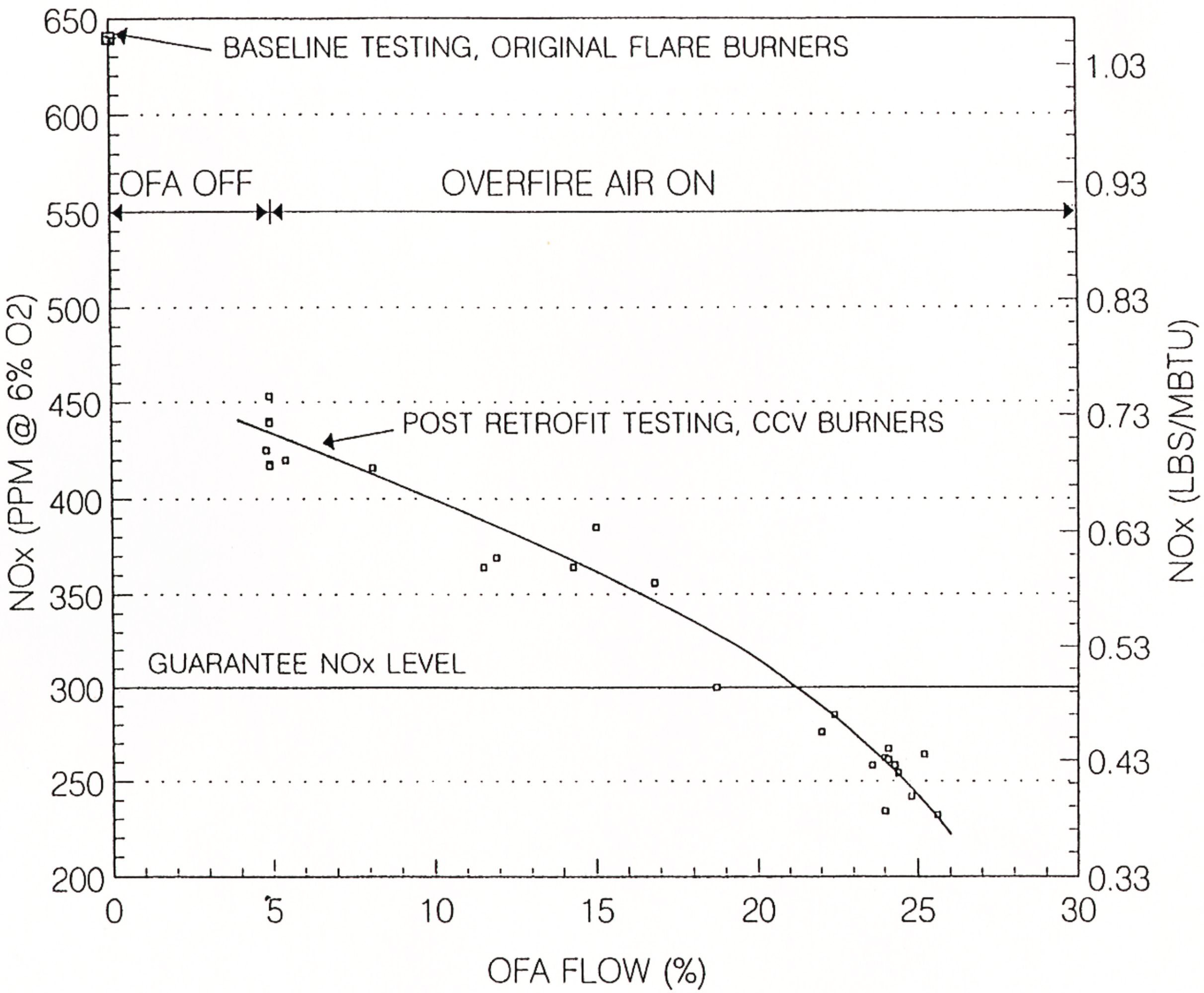

Figure 3. NO_x Emission Test Results at Full Load
300 MW Utility Boiler

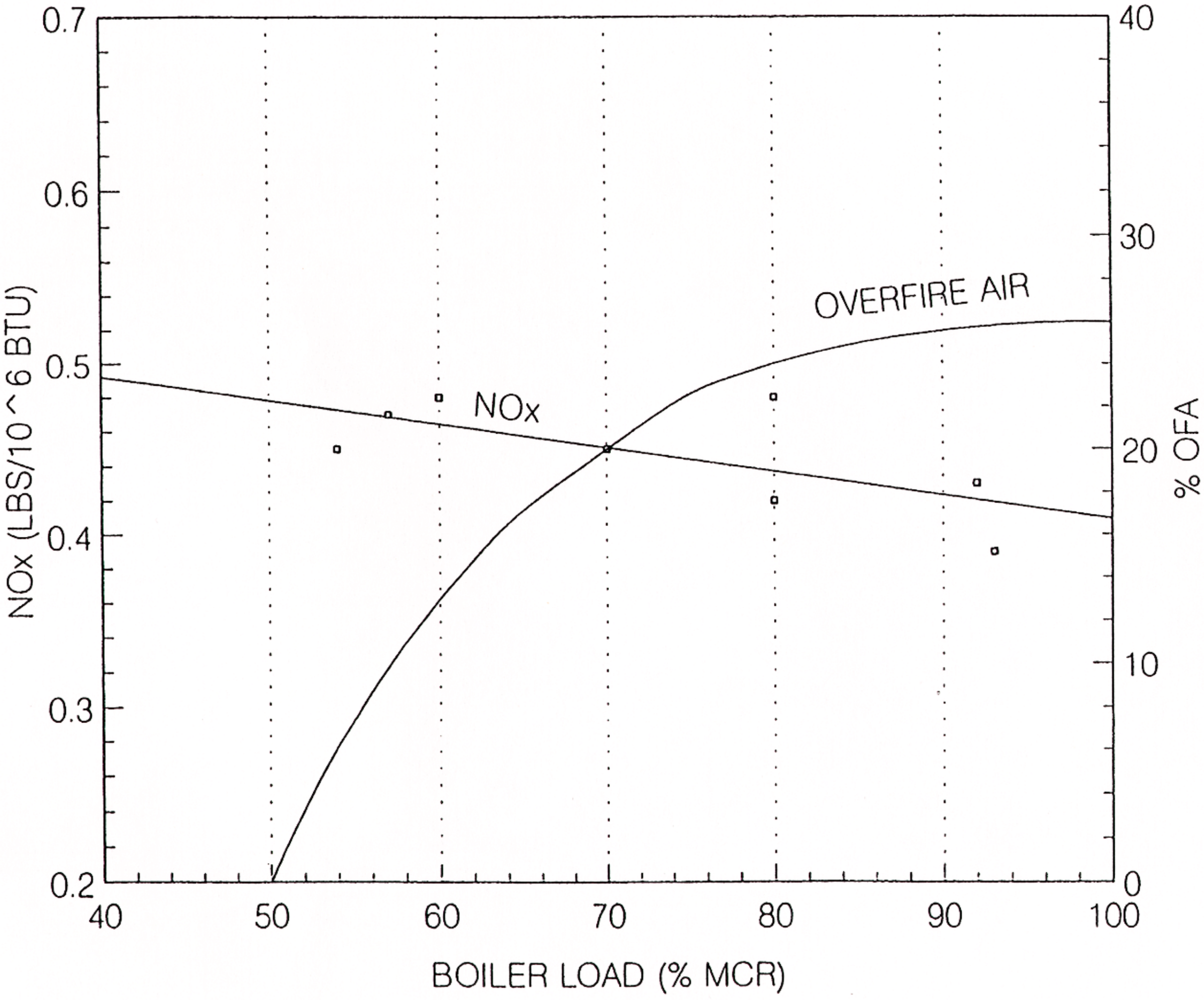

Figure 4. NO_x vs. Load - 300 MW Utility Boiler

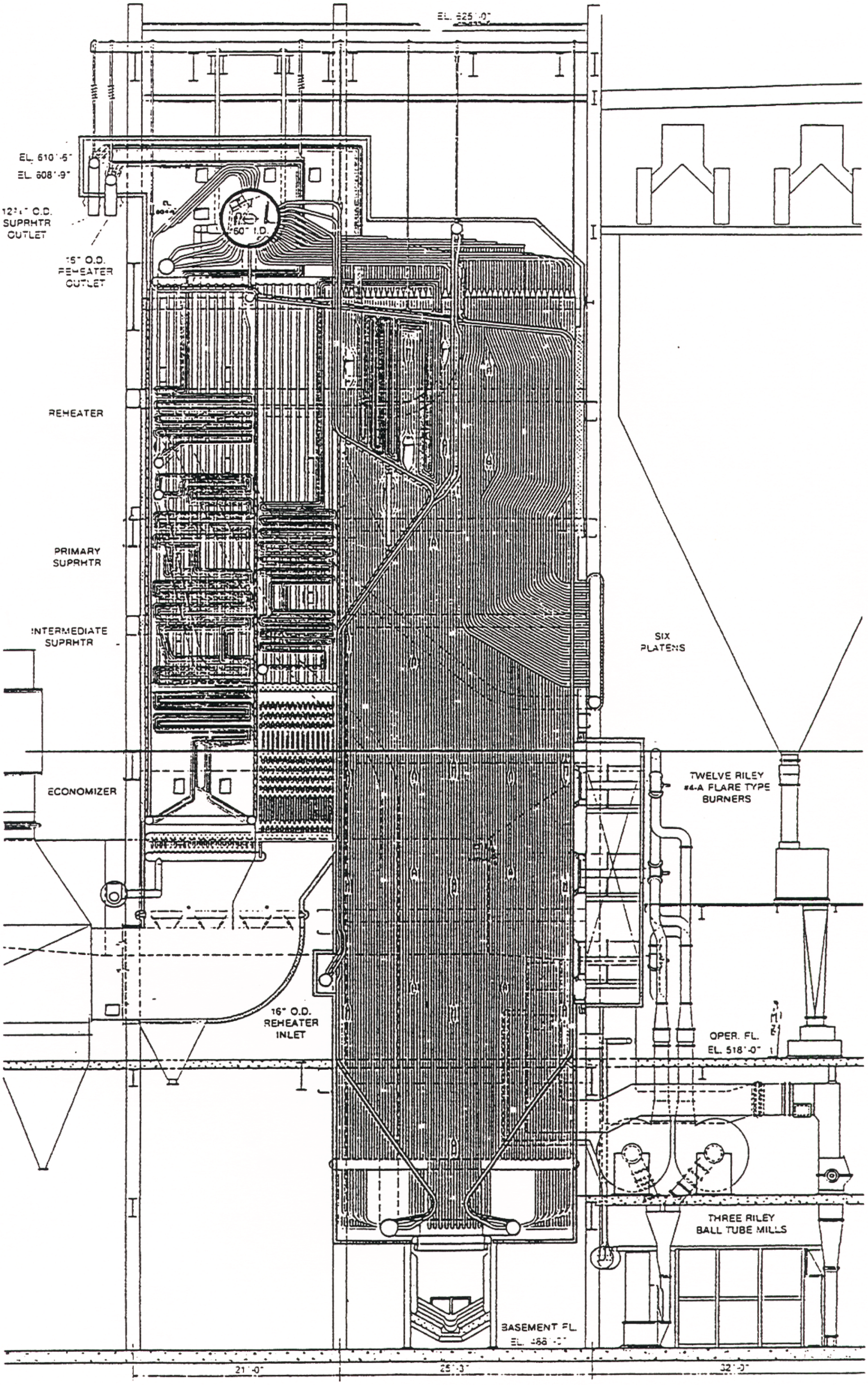

Figure 5. Public Service of Indiana Wabash River Unit 5

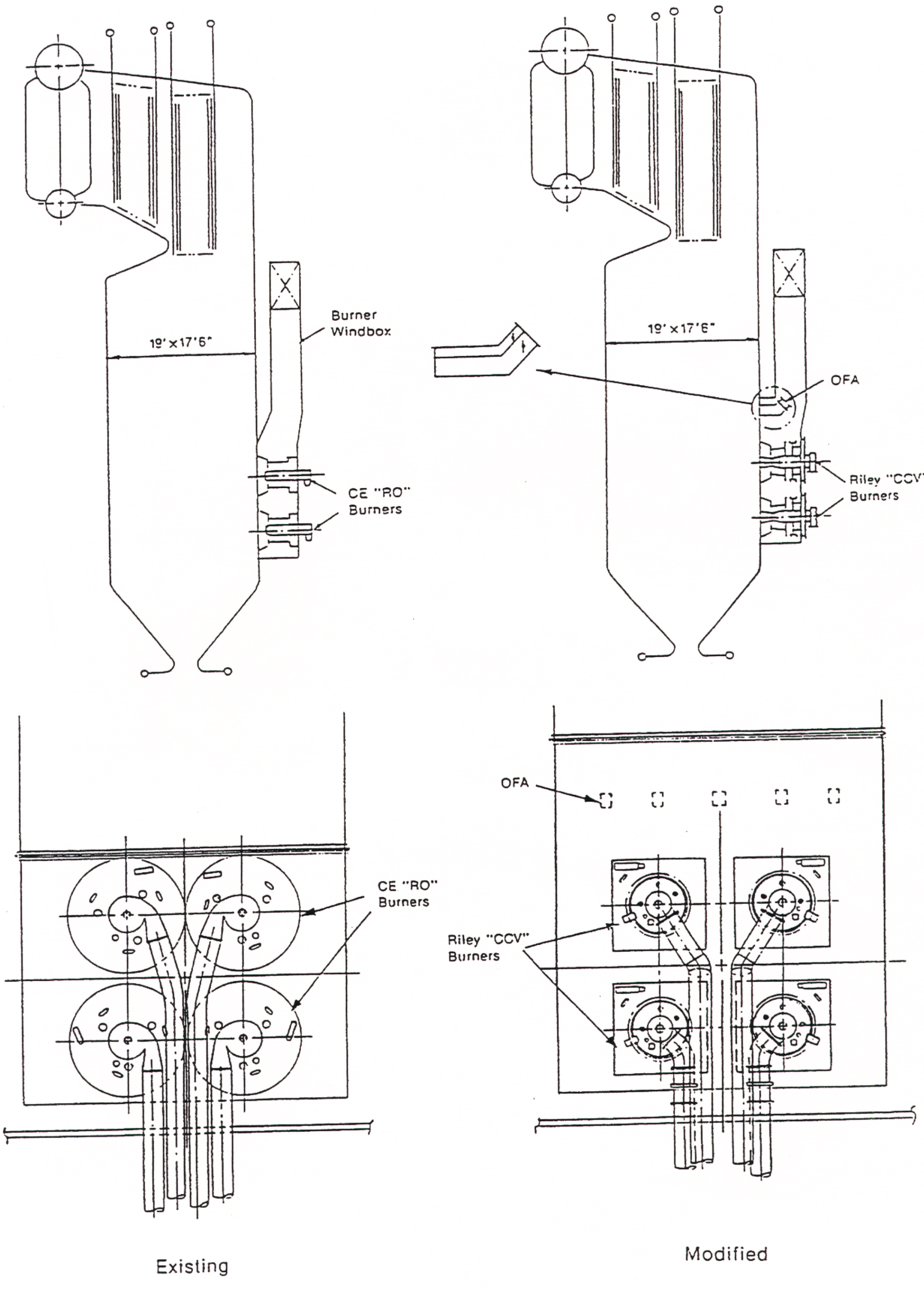

Figure 6. City of Vineland Howard Down Unit 10 Low NO_x Combustion System Retrofit

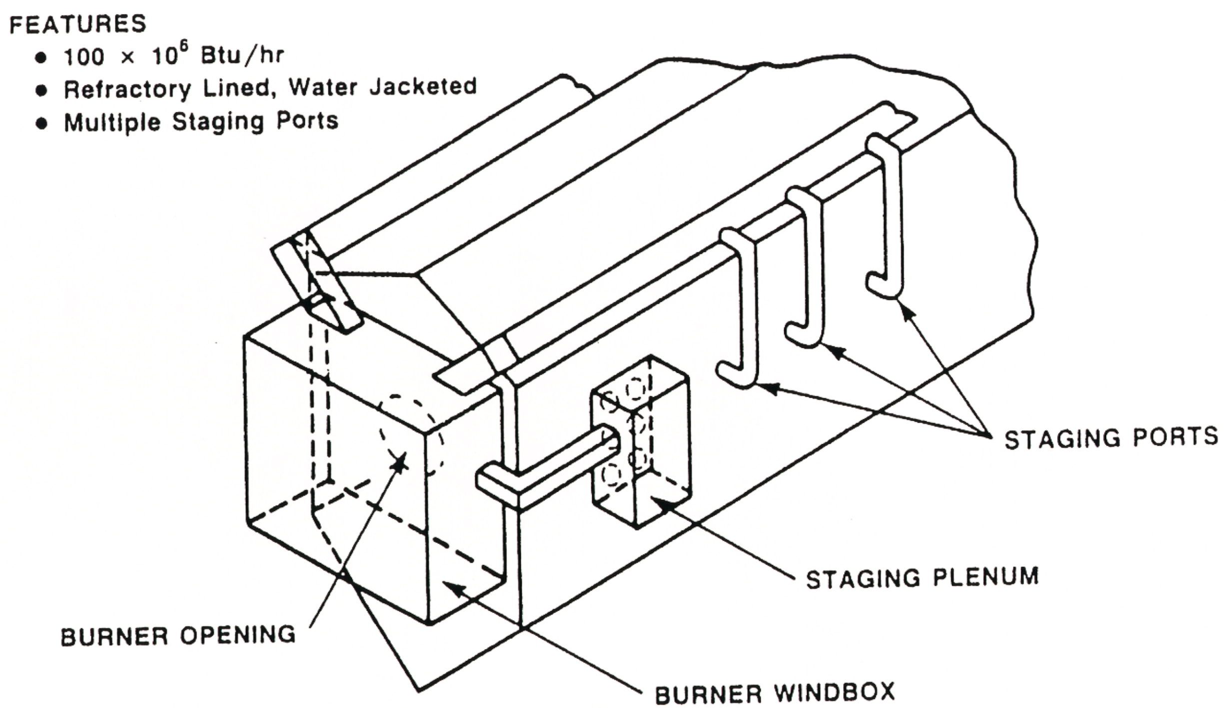

Figure 7. Riley Coal Burner Test Facility (CBTF)

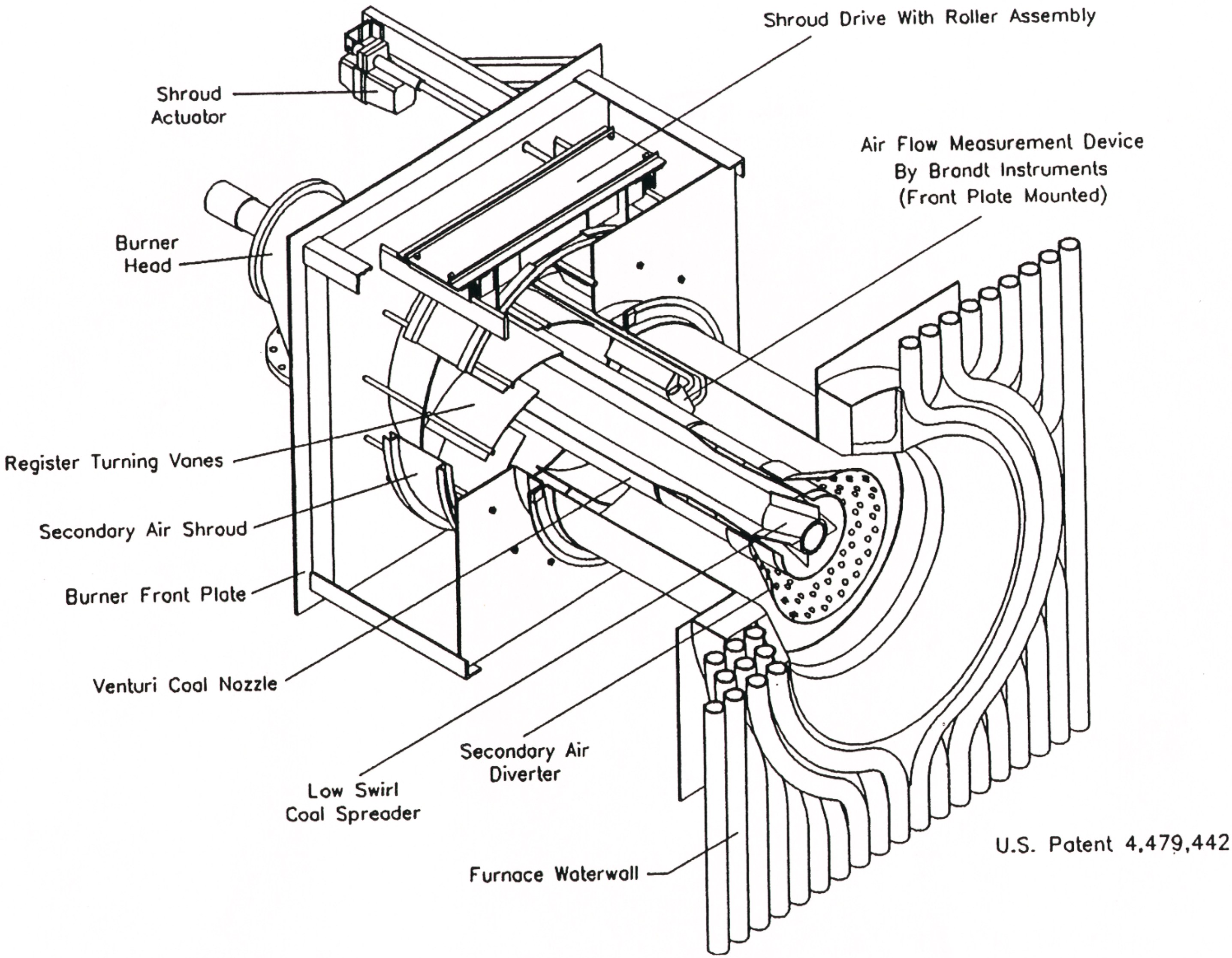

Figure 8. Riley Low NO_x CCV™ Burner with Secondary Air Diverter

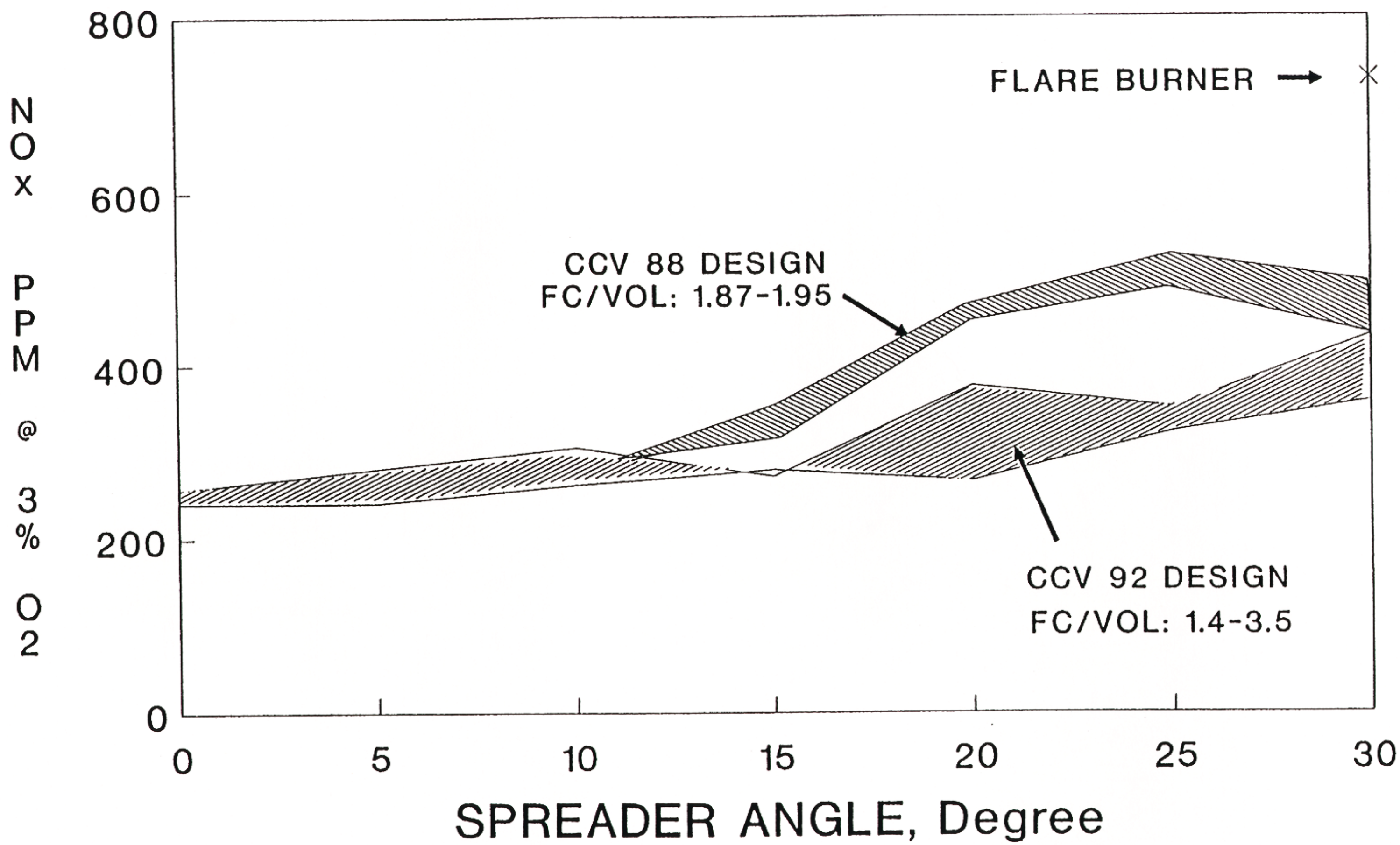

Figure 9. The Effect of Coal Spreader Angle on NO_x Emissions
CBTF Pilot Test Results

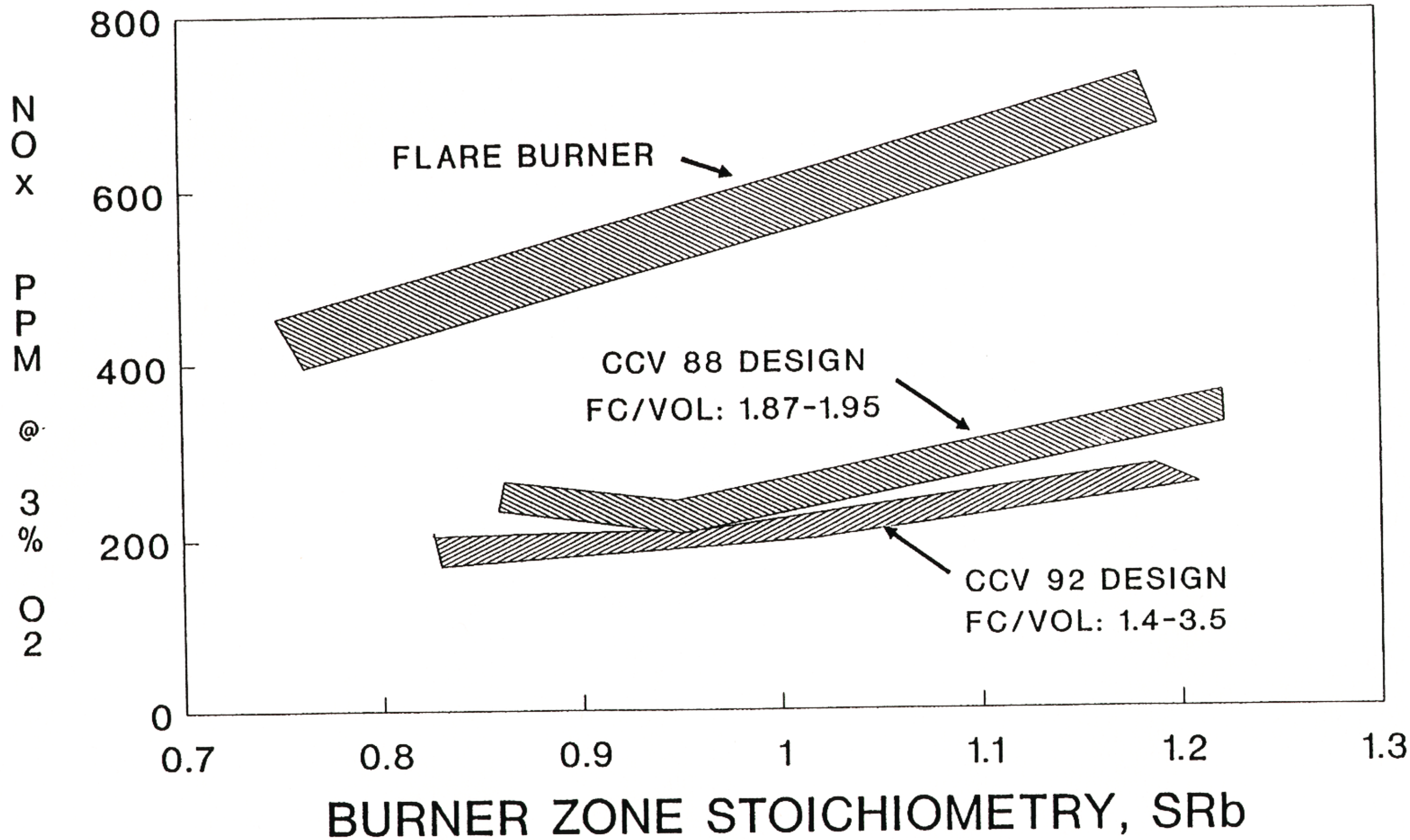

Figure 10. The Effect of Air Staging on NO_x Emissions
CBTF Pilot Test Results

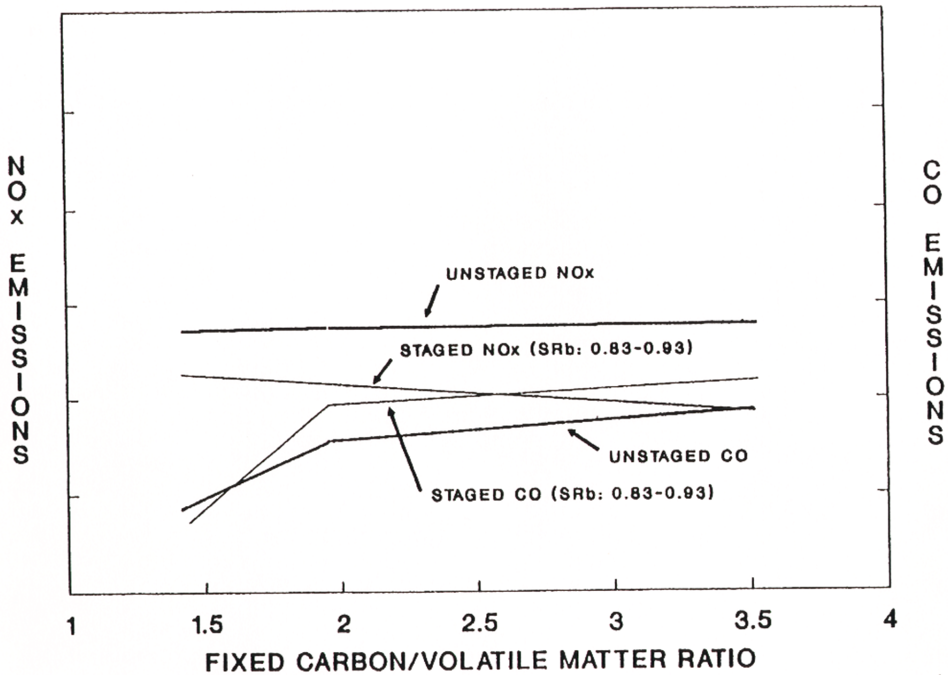

Figure 11. The Effect of Fuel Factor (FC/VM Ratio) on NO_x and CO Emissions - CBTF Pilot Test Results