Technical Publication

Applications and Further Enhancement of the Low NO_X CCV® Burner

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ABSTRACT

Riley Stoker has been supplying low NO_x combustion systems technology to the boiler industry, both new and retrofit, since the early 1980s. Utilizing the Riley Controlled Combustion Venturi (CCV®) Burner for coal fired boiler applications, NO_x emissions have been reduced by 50-70% from pre-NSPS levels without deterioration in boiler performance.

Results of recently retrofitting this technology to two coal fired utility boilers will be discussed. The field data presented includes emissions and boiler performance data comparing both pre and post-retrofit test results. The application of this technology to new utility boilers having NO_x emission requirements down to 0.3 lbs / 10^6 Btu will be presented.

Pilot results of testing a 100 x 10^6 Btu / hr CCV® Burner incorporating new advanced design enhancements on several eastern bituminous coals in DB Riley's combustion test furnace are presented. Of particular interest is the improvement in NO_x reduction capability without the need for overfire air. The CCV® Burner's satisfactory performance over a wide range of fuel properties is discussed.

Field emissions data for an advanced low NO_x coal burner currently in development at DB Riley and our parent company, Deutsche Babcock, are also presented.

INTRODUCTION

During the past two years, industry activity involving retrofit of low NO_X burners to utility boilers has been increasing at an exponential rate. Typically, boiler manufacturers are being required to provide low NO_X burner technology effective at reducing NO_X emissions from pre-NSPS levels of 1.0-1.5 lb/10^6 Btu to < 0.5 lb/10^6. Some state and local levels are less while new boiler requirements are averaging 0.3 lb/10^6 Btu or lower.

Boiler manufacturers are thus faced with the challenge of meeting these low emission levels without any detrimental impact on overall boiler performance. Consequently, the technology must continually be updated, enhanced and improved upon to meet the demands of tomorrow's market.

This paper will focus on DB Riley's experience with retrofit installations and will discuss our plans for meeting the strict performance requirements of the future.

FIELD EXPERIENCE

Since 1990, DB Riley has proposed and sold many utility customers low NO_X combustion systems technology utilizing our patented CCV® Burner[1] with or without an overfire air system. Figure 1 is a schematic drawing of the CCV® Burner, shown with the latest design enhancement, a secondary air diverter. A detailed description of the CCV® Burner and its theory of operation was reported in technical papers presented last year.[2,3]

As discussed later, the diverter causes the secondary air to flow away from the primary combustion zone, thus expanding the reducing zone at the burner discharge. This promotes greater devolatilization of the coal in a reducing environment which contributes to greater NO_X reduction. The diverter improves NO_X reduction capability 25-30%. It is used primarily on those applications without the need for overfire air (OFA) or with a minimal amount of air staging (SR_B > 1.0).

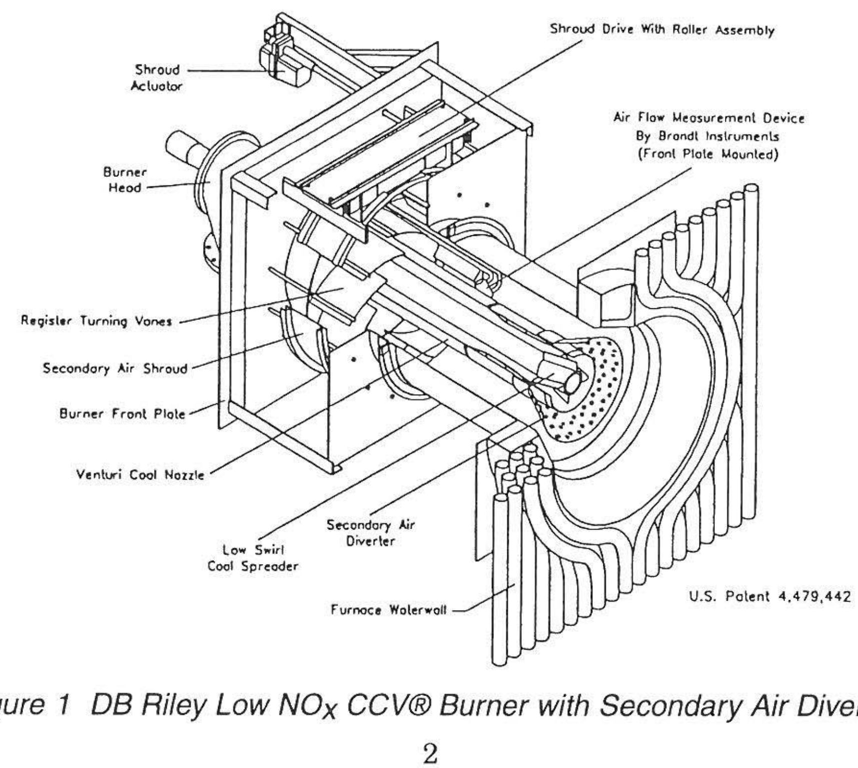


Figure 1 DB Riley Low NO_X CCV® Burner with Secondary Air Diverter

Within the next two years, DB Riley will have nearly 5000 MW of installed low NO_x burner capacity and over 450 burners in operation. The retrofit installations include DB Riley, Babcock and Wilcox, and Foster Wheeler boilers. The largest retrofit, scheduled for the fall of this year, will be the installation of DB Riley CCV® Burners on a 600 MW B&W boiler presently equipped with pre-NSPS B&W cell burners.

Results of recently retrofitting DB Riley low NO_x combustion systems on two utility boilers are discussed below.

TAIWAN POWER COMPANY LINKOU UNIT 1

This boiler is a DB Riley 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. Figure 2 shows a drawing of the original boiler installation. Pulverized coal is supplied by three double ended ball tube mills which feed eighteen burners arranged in three rows of six 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.

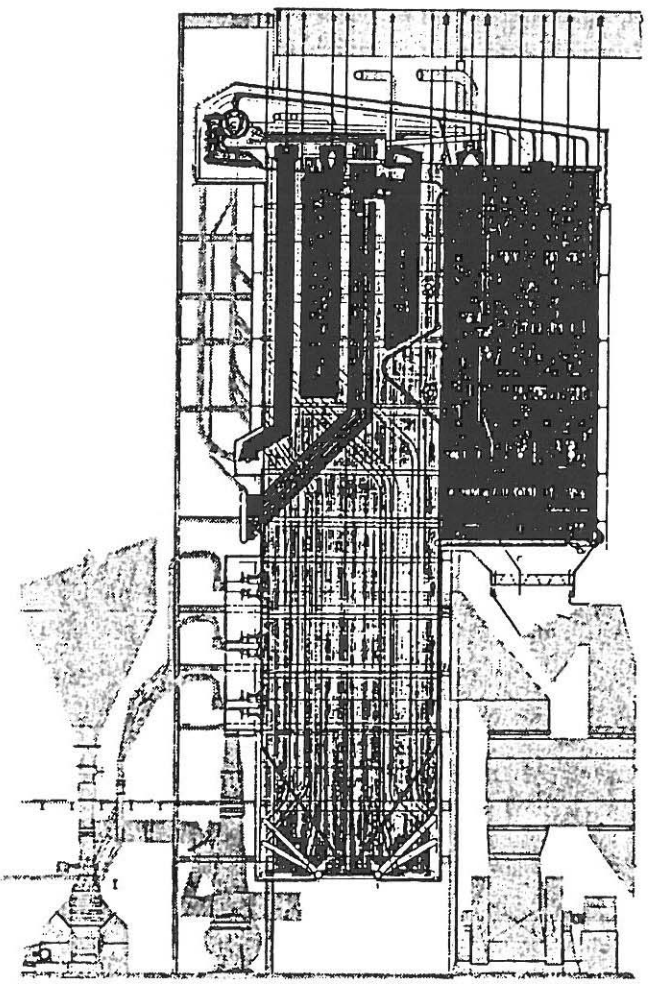


Figure 2 Taiwan Power Company, Linkou Unit 1 Original Boiler Configuration

In the spring of 1992, the unit was retrofitted with a new DB 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 DB Riley installed included eighteen low NO_X CCV® Burners without secondary air diverters each rated for 155 million Btu/hr, and an advanced overfire air system. As shown in Figure 3, the overfire air system consisted of a separate header duct feeding eight OFA ports on the front wall and four 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 DB 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 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, we 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 substoichiometrically for controlling NO_X.

During the design phase of this retrofit project, a 1/12th scale Plexiglas flow model was constructed and tested at DB 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

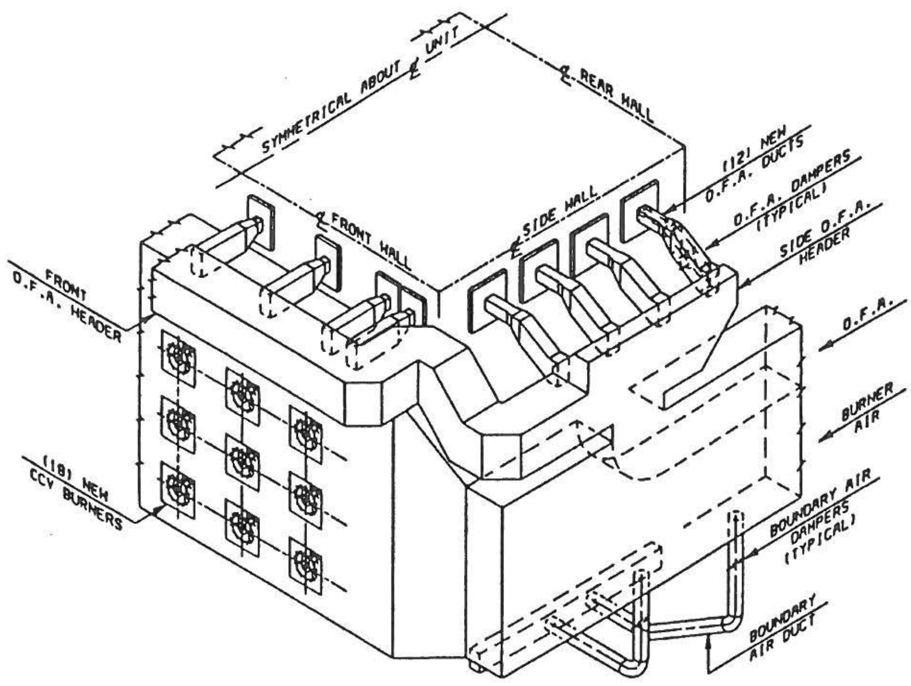


Figure 3 Low NO_X Combustion System Retrofit for Taiwan Power Company, Linkou Unit 1

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 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 in August, 1992 to evaluate performance of the new low NO_X combustion system. Results are summarized in Table 1. The NO_X emissions decreased from 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 1, 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 2 summarizes the fuel analysis for this coal.

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	–
Econ. Gas Out. Temp., °F	–	650	635	–
AH Gas Out. Temp., °F	–	291	297	–
Boiler Efficiency, %	–	88.12	89.25	–
Coal Fineness				
% - 50 Mesh	96.9	94.0	95.5	95.5
% - 200 Mesh	67.8	64.3	66.1	66.1

Table 1 Taiwan Power Company Linkou Unit 1 Emissions Test Relsults

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 2 Taiwan Power Company Linkou Unit 1 Fuel Analysis

Figure 4 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

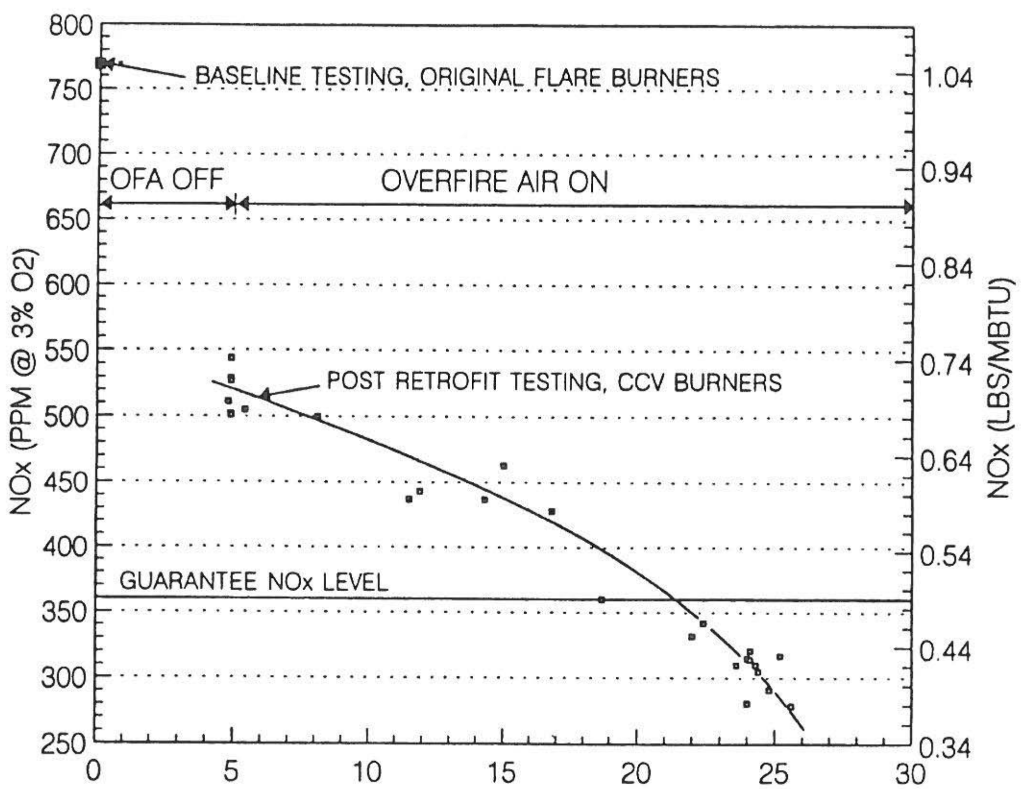


Figure 4 The Effect on Air Staging on NO_x Emissions, 300MW Utility Boiler

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 last 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 5 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.

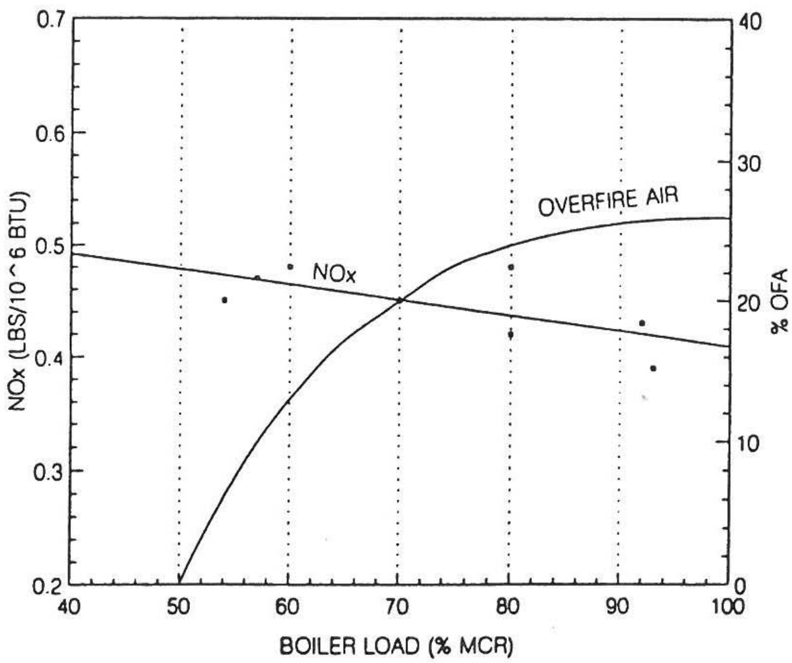


Figure 5 The effect of boiler load on NO_x Emissions 300 MW Utility Boiler

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 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 2

CCV® Burners and an OFA system were installed last fall on Public Service of Indiana's Wabash River Unit 2 to reduce NO_x emissions. The unit is a FW pulverized coal fired steam generator with a rated capacity of 700,000 pph steam flow, at a design pressure of 1500 psig and final steam temperature of 1005°F superheat and 1005°F reheat. Pulverized coal is supplied by two FW ball tube mills equipped with exhauster fans feeding twelve burners. The unit, shown in Figure 6, is rated to generate 100 MW of electrical power. However, because of coal quality and mill capacity limitations, the unit typically operates at 85-90 MW. Furnace dimensions are 44'-8" W x 22'-2" D.

As shown in Figure 7, the low NO_X system retrofit included low NO_X CCV® Burners and an OFA system. The CCV® Burners incorporated the new secondary air diverters.

The OFA system design and operation was similar to the Taiwan Power installation with the exception of having OFA ports in the furnace side walls. The goal of the retrofit project was to reduce NO_X emissions to < 0.45 lb/10^6 Btu. Baseline testing, to quantify pre-retrofit emission levels, was not performed.

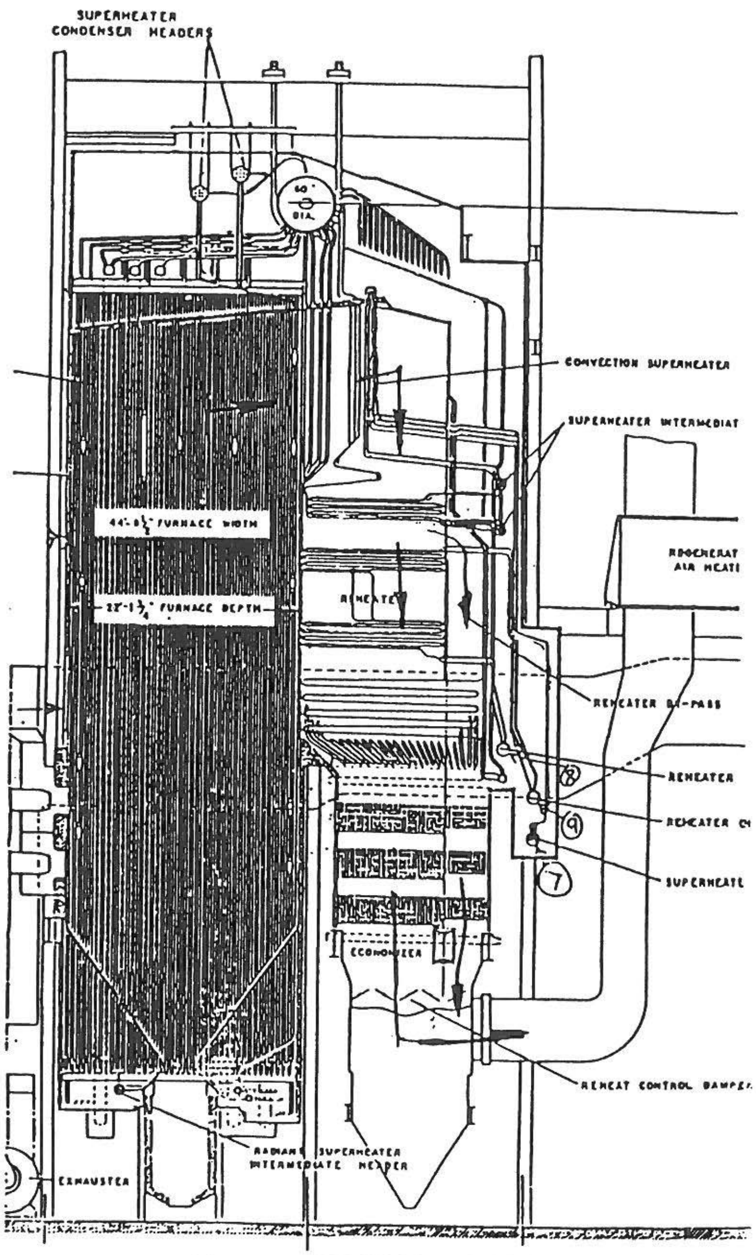


Figure 6 PSI Wabash Unit 2
Original Boiler Configuration

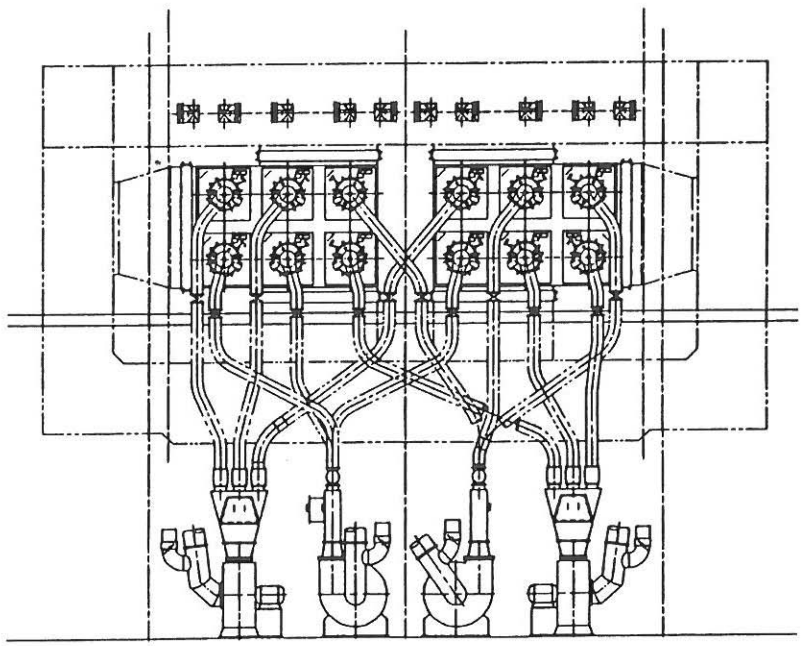


Figure 7 Low NO_X Combustion System Retrofit for PSI Wabash Unit 2

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 8, acceptable emission levels were achieved while operating with burner zone stoichiometric ratios, SR_B above 1.0. Figure 9 shows how NO_X emissions can be controlled to a relatively constant level with variations in boiler load.

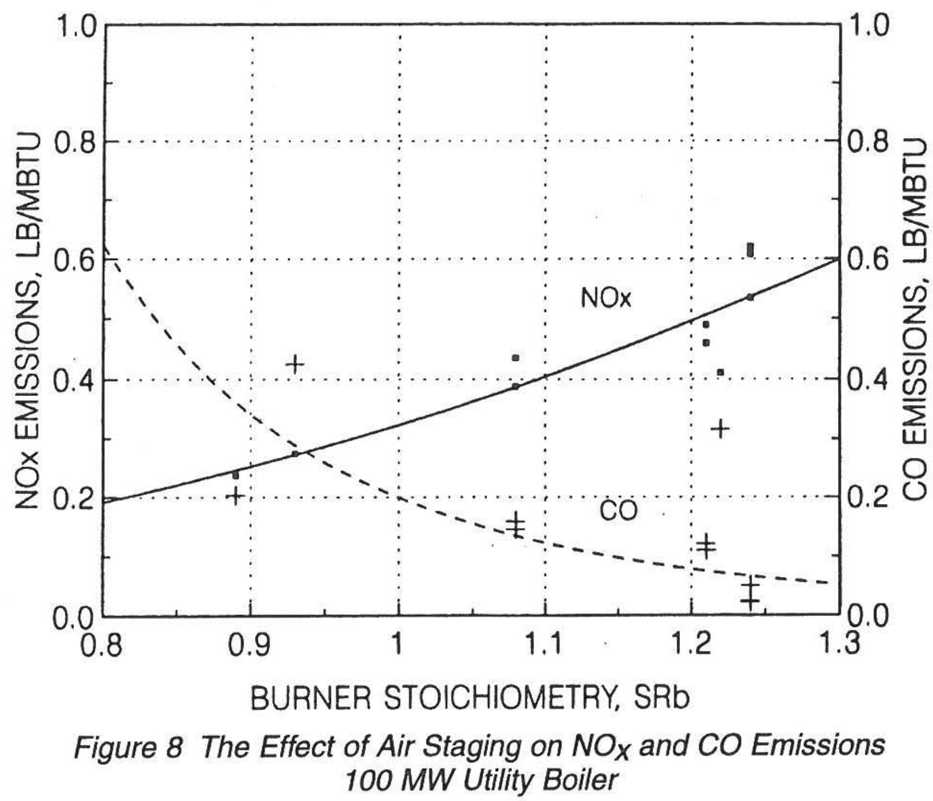


Figure 8 The Effect of Air Staging on NO_X and CO Emissions 100 MW Utility Boiler

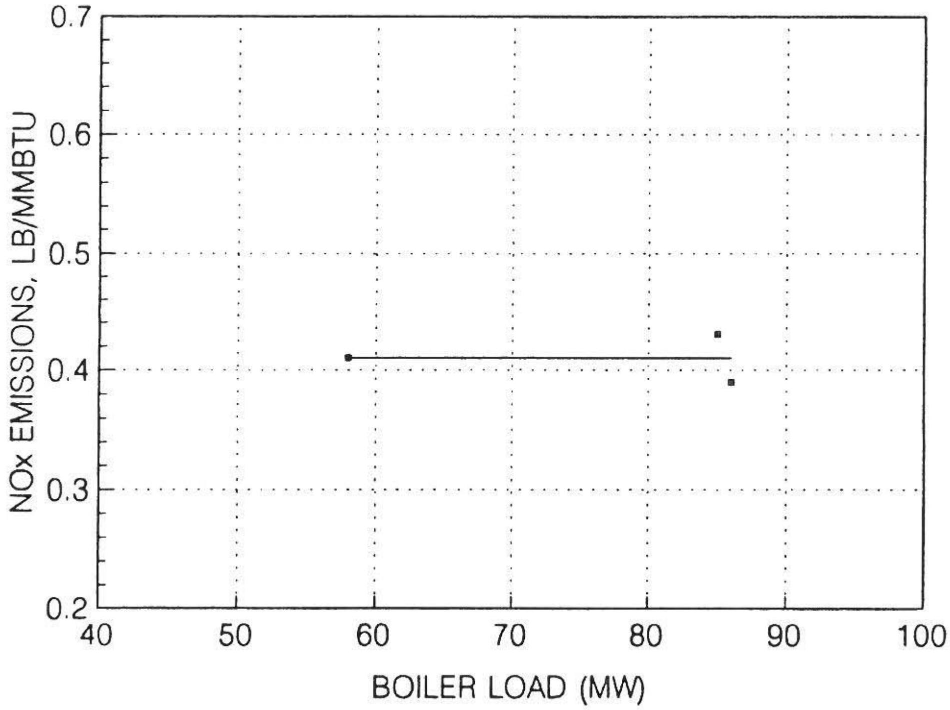


Figure 9 The Effect of Boiler Load on NO_x Emissions
100 MW Utility Boiler

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. Plans are to install, in the spring of 1993, larger coal nozzles to accommodate the higher A/C ratios. CO emissions and the amount of unburned should subsequently decrease. Diagnostic testing also showed a significant O_2 imbalance at the economizer exit and possible furnace infiltration or air in-leakage. This could also potentially contribute to the CO and LOI.

The results of this testing emphasized the importance of fully understanding the complete fuel burning system including mill operation prior to the design of a low NO_x retrofit. Pre-NSPS burners were much more forgiving to differences between design and actual operation than today's low NO_x burners.

NEW BOILER NO_x CONTROL

DB Riley is currently in the construction phase of a new industrial boiler designed to limit NO_x emissions to 0.3 lb/10^6 Btu when burning an eastern bituminous coal. The steam generator, shown in Figure 10, is an opposed fired unit rated at 700,000 lb/hr main steam flow and superheater outlet conditions of 955°F and 1500 psig. The furnace dimensions are 24'-4" W x 26'-O" D.

The firing equipment designed to meet this low NO_x emission requirement includes Riley low NO_x CCV® Burners, an overfire air system, compartmentalized windbox and lower furnace boundary air. A total of twelve low NO_x burners will be installed in the furnace with six burners on both the front and rear walls. However, rather than directly opposing the burners, as normally done in conventional designs, the burners between the front and rear walls, shown in Figure 11, are staggered or offset horizontally.

This unique firing arrangement has recently been used in Europe by Deutsche Babcock to achieve low NO_x emissions. The staggered firing pattern will minimize flame interaction between the opposing flames, reduce peak flame temperature and mixing and subsequently minimize NO_x formation.

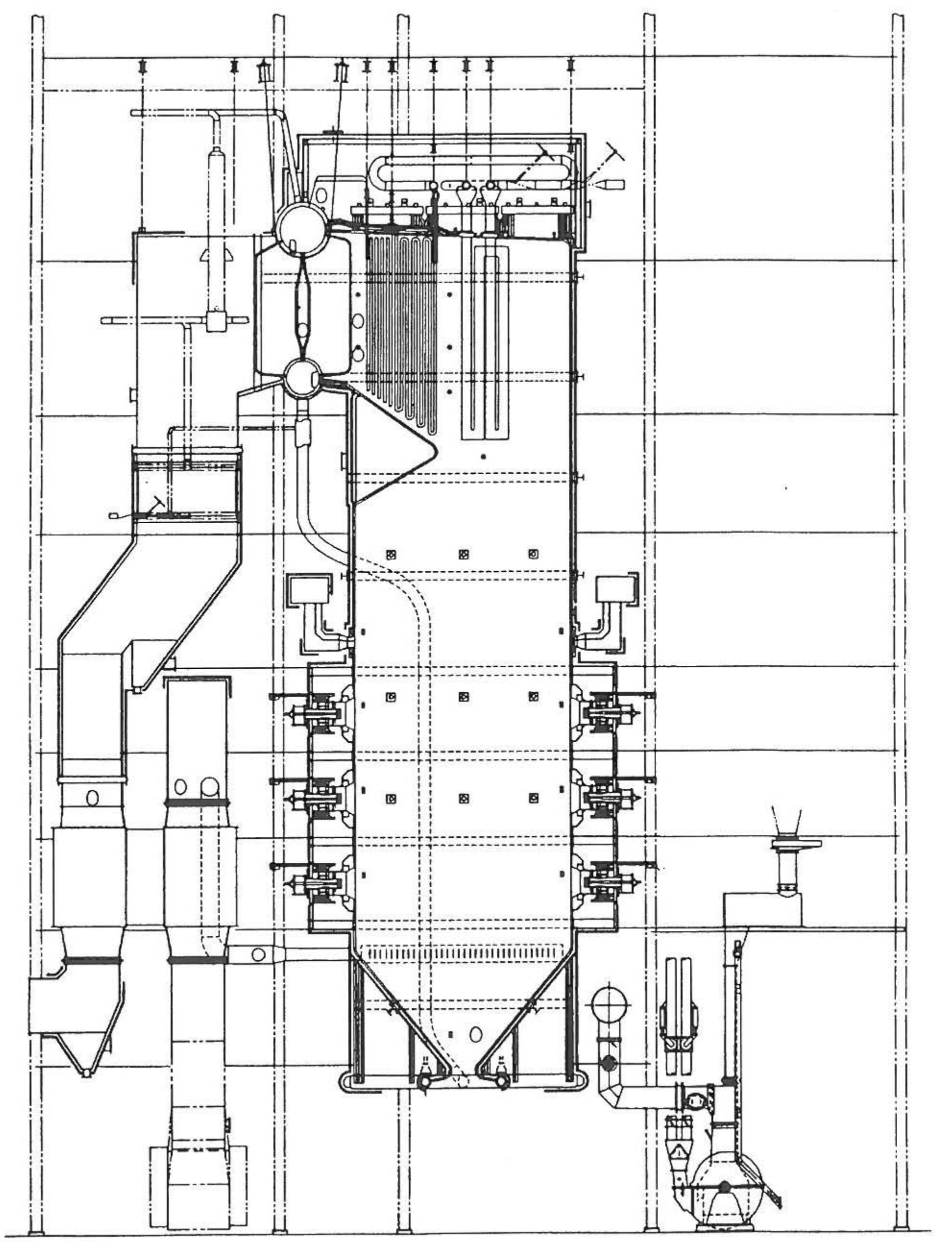


Figure 10 New Industrial Boiler Configuration

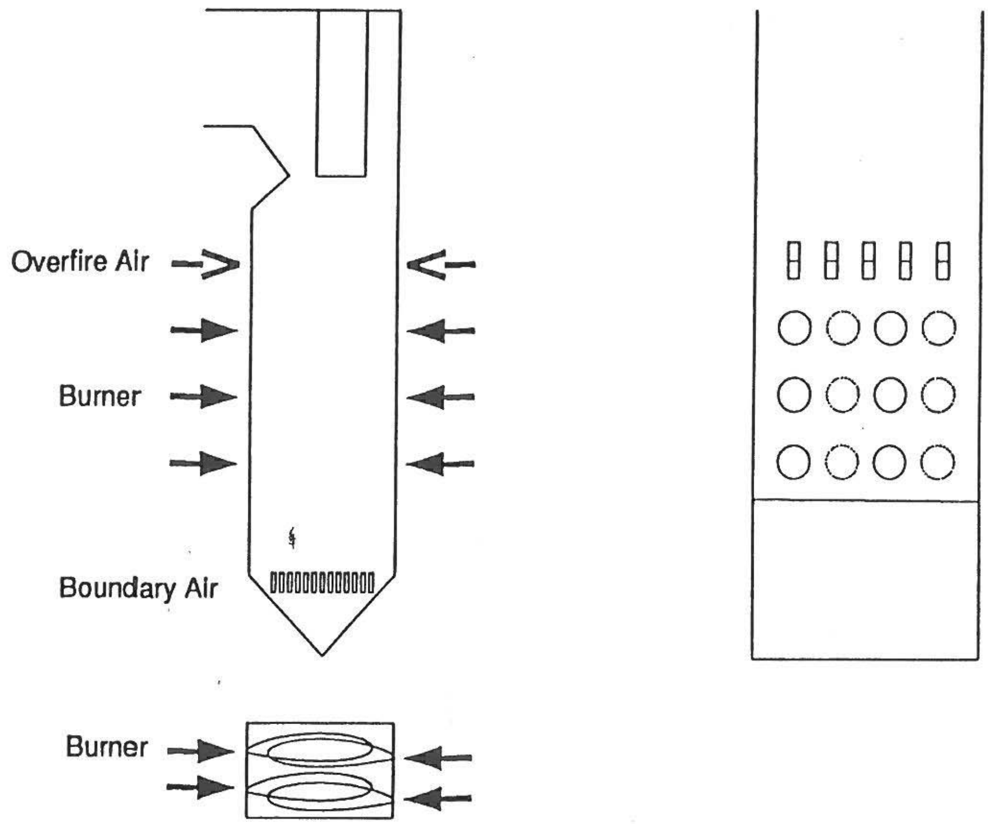


Figure 11 Unique Burner Arrangement and Firing Patterns Used to Control NO_X Emissions on a New Industrial Boiler

A large portion of the total NO_X emission will be minimized by the CCV® Burner alone while the remaining NO_X will be minimized by use of the overfire air system. The OFA system, designed to introduce approximately 15-25% of the total combustion air into the furnace above the main burners, will be equipped with airfoils and dampers for accurate flow measurement and control throughout the boiler load range.

To minimize the potential for lower furnace waterwall corrosion as a result of operating the main burners substoichiometrically, boundary air will be introduced low in the furnace. The boundary air will be introduced through waterwall openings on both sidewalls just below the furnace bottom hopper bend line. This air will provide a blanket of oxygen to maintain a localized oxidizing environment adjacent to the side waterwall tubes thus mitigating the potential for corrosion.

To ensure efficient carbon burnout is maintained while operating at this low NO_X emission requirement, special emphasis was placed on the pulverizer system design. Three DB Riley ATRITA® Pulverizers were selected for this unit because of their compact design, easy maintenance, excellent history of availability and quick response to load changes. The pulverizers were sized conservatively to ensure a product fineness exceeding 99% passing a 50 mesh sieve and 75% passing 200 mesh would be maintained for a wide range of coal properties. The resulting pulverizers have 25% greater grinding capacity than what normally would have been selected for "standard" pulverizer fineness requirements.

Special consideration was also given to the design of the combustion air supply system to ensure efficient combustion is maintained. The burner windbox was partitioned internally to enable individual flow control and accurate determination of the combustion air to the burners. This degree of sophistication has again been used in Europe for several years to more effectively control the stoichiometry for each burner. It is used today by DB Riley on new domestic installations having stringent NO_X emission requirements.

Commercial operation of this new industrial boiler is expected to commence in the first quarter of 1994.

CCV® BURNER DESIGN ENHANCEMENT

As reported in previous technical papers,[2,3] a prototype CCV® Burner was tested last year in the Riley Coal Burner Test Facility (CBTF). The Riley CBTF, located in Worcester, Massachusetts, shown in Figure 12, is a horizontal tunnel furnace with the test burner mounted on one end and the exhaust exiting the opposite end. Testing was performed on the CCV® Burner at 100 x 10^6 Btu/hr rated capacity while firing four different eastern bituminous coals. The coals were specially selected to provide a wide range in volatile content from 18.9% to 35.7%.

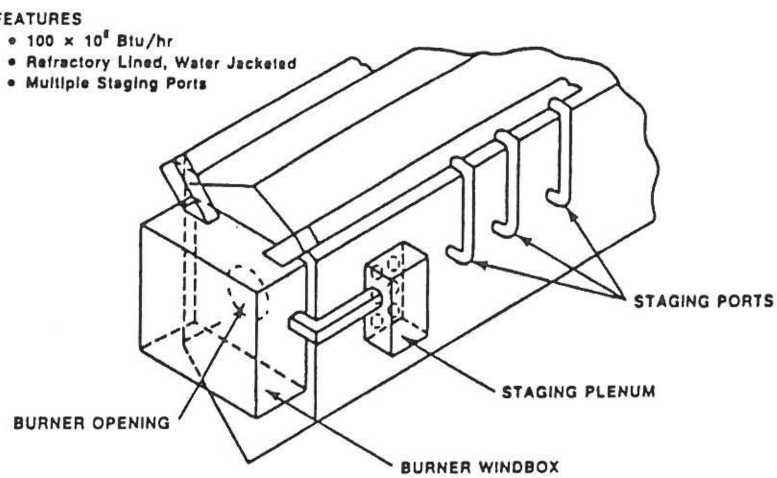


Figure 12 Riley Coal Burner Test Facility (CBTF)
100 MM Btu/hr Capacity

The primary purpose of the testing was to develop design enhancements for the CCV® Burner to achieve greater NO_X reduction without the requirement for OFA. The other purpose was to evaluate the effect of various fuel characteristics on emissions and overall burner performance.

The most significant design enhancement developed during the testing was the inclusion of a secondary air diverter mounted adjacent to the discharge end of the coal nozzle. Figure 1, shown previously, illustrates the CCV® Burner design with the new secondary air diverter. The secondary air diverter causes 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 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 13 shows a comparison of NO_X data collected as a function of different coal spreader angles between the original CCV® Burner and the CCV® Burner with secondary air diverter. 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%.

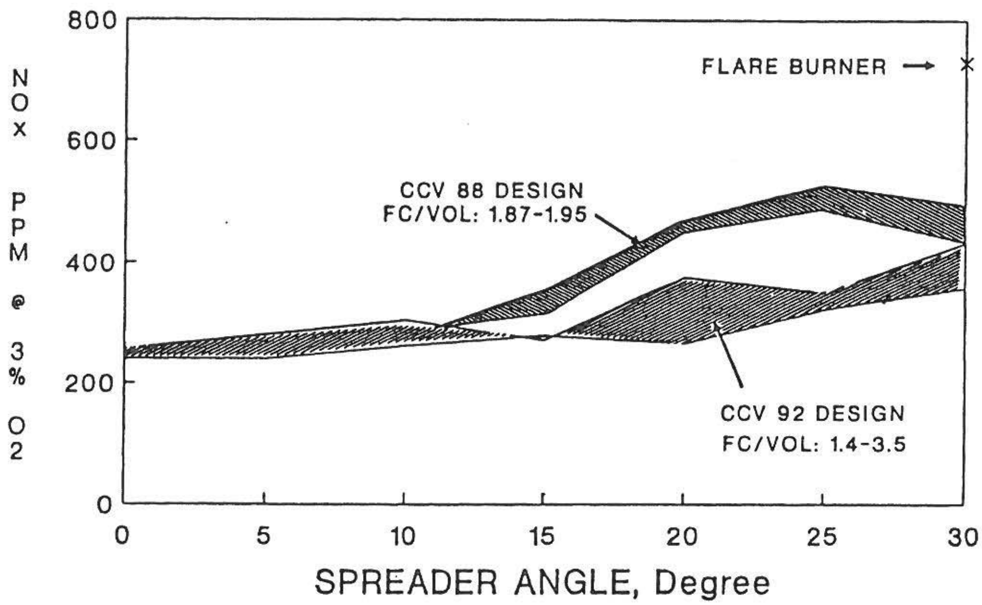
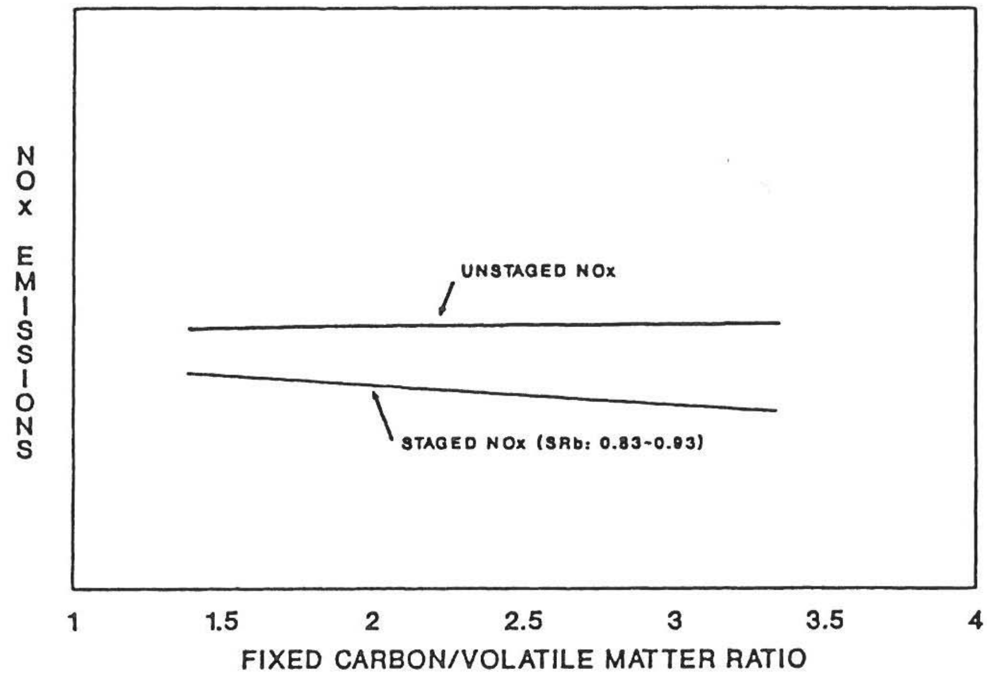


Figure 13 The Effect of Coal Spreader Angle on NO_X Emissions
CBTF Pilot Test Results - Unstaged Operation

A data point representing the level of NO_X measured in the CBTF from Riley's pre-NSPS highly turbulent flare type burner is also shown in Figure 13 for comparison. This testing showed the potential for the CCV® Burner to reduce NO_X emissions > 60% without the need for OFA ports.

Figure 14 shows the effect of variations in fuel factor or FC/VM ratio on NO_X and CO emissions performance. 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.[5] If anything, the data collected on the latest CCV® Burner 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.



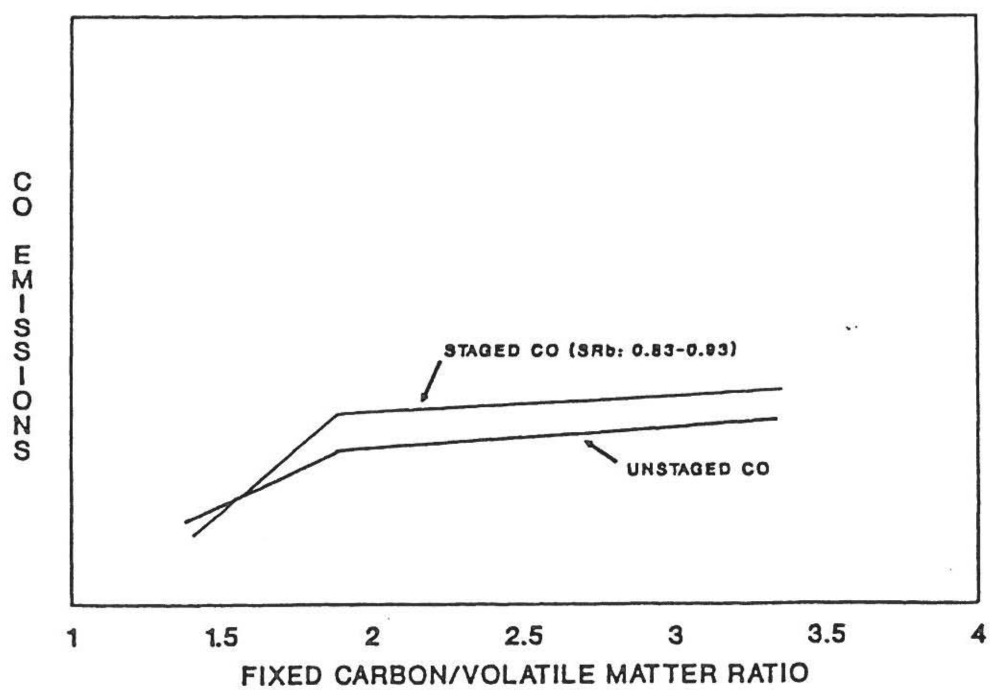


Figure 14 The Effect of Fuel Factor (FC/VM Ratio) on NO_X and CO Emissions CBTF Pilot Test Results

ADVANCED LOW NO_X COAL BURNER DEVELOPMENT

DB Riley and its parent, Deutsche Babcock, are also working on the development of an advanced low-NO_X coal burner for wall fired boilers. A new burner, known as the DS (Drallstufen) burner, is being demonstrated at a power station in Völklingen, Germany.

The power station steam generator has an electrical output of 170 MW and also provides steam for district heating. It is equipped with eight DS pulverized coal burners arranged on two levels on opposite walls. Each burner is sized to provide > 250 x 10^6 Btu/hr heat input. The opposed fired low NO_X firing system also includes a single level of overfire air. As is common in many European systems, the air flow to each burner is individually controlled. The fuel for the power station is high volatile, bituminous coal with a volatile content of 40% on a dry ash free basis.

The DS burner is a swirl staged burner with two coaxial air streams (secondary and tertiary) surrounding the coal nozzle. As in our most recent CCV® Burner design, air diverters or deflectors are used to further control the mixing of the separate air streams in the primary flame zone. As shown in Figure 15, German field tests have demonstrated an ability to operate at NO_X emissions of less than 250 ppm or 0.34 lb/10^6 Btu without the use of overfire air.[6] Additional tests have shown that NO_X levels of less than 175 ppm, or 0.24 lb/10^6 Btu can be achieved with the DS burner with moderate amount of overfire air (i.e., SR_B = 0.96).

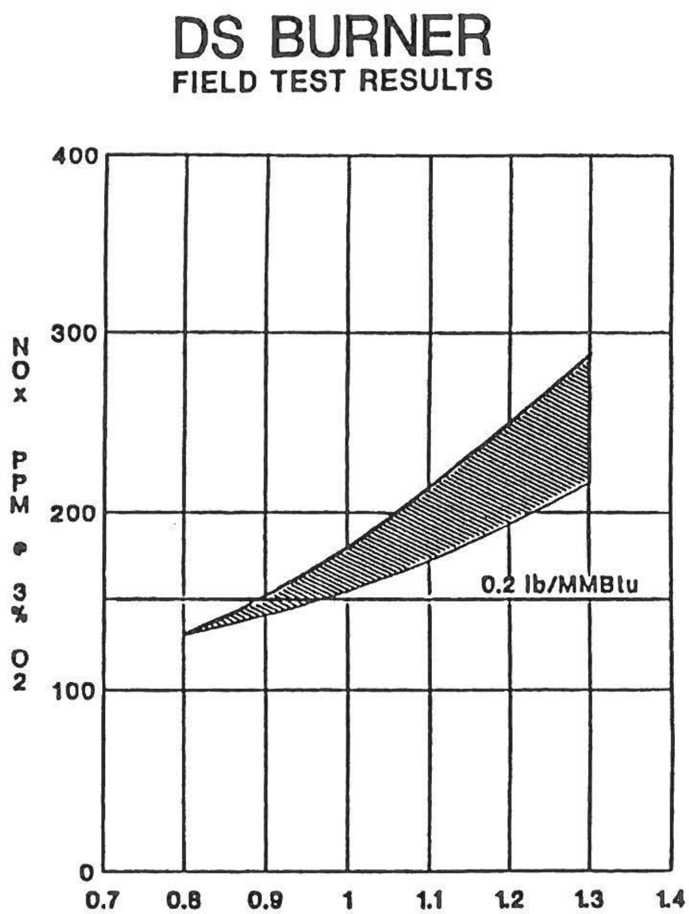


Figure 15 German Field Test Results from Riley/DB Advanced Low NO_X Coal Burner

These initial data are based on short term testing. Also, German field operating conditions may not be fully representative of U.S. boiler operation. Because of this, DB Riley and Deutsche Babcock are currently performing further development tests on an 80 million Btu/hr prototype DS burner in the DB Riley Coal Burner Test Facility. Tests are being performed on several U.S. bituminous coals of varying volatile content. The objective of the test program is to better understand the influence of design parameters such as coal nozzle and burner exit geometry, and secondary air stream aerodynamics on overall burner performance. A CCV® coal nozzle is also being tested in this double-register separated air design configuration. Based on the results of the test program, which is scheduled to be completed early this summer, DB Riley will prepare a burner design for U.S. burner windbox applications.

SUMMARY

DB Riley has successfully retrofitted the Controlled Combustion Venturi (CCV®) Burner on several coal fired utility boilers. The retrofits have, in most cases, involved installing the original CCV® Burner design with an overfire air system. NO_X reduction performance has exceeded 60% from pre-NSPS levels without deterioration in boiler performance.

More recently, the CCV® Burner, incorporating the secondary air diverter, has been retrofitted on one utility boiler. NO_X emissions < 0.5 lb/10^6 Btu were measured during unstaged operation and < 0.4 lb/ 10^6 Btu with only a minor amount of air staging (SR_B > 1.0).

Laboratory testing has shown the CCV® Burner to be relatively insensitive to variations in coal properties in regard to NO_X emissions. CO emissions and carbon burnout are affected much more significantly.

DB Riley is pursuing further improvements in low NO_X coal burner technology. Field testing of an advanced low NO_X coal burner currently in development by DB Riley and Deutsche Babcock has demonstrated Nox levels of < 0.24 lb/10^6 Btu during commercial operation. The inclusion of CCV® Burner technology such as the venturi coal nozzle and air register shrouds into this burner system is currently being tested for the U.S. boiler industry.

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