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Latest Developments and Application of DB Riley's Low NO_x CCV® Burner Technology

by

Craig A. Penterson
Manager, Fuel Equipment Design
RILEY POWER INC.
a Babcock Power Inc. company
(formerly DB Riley, Inc.)

Terence R. Ake
Staff Engineer
RILEY POWER INC.
a Babcock Power Inc. company
(formerly DB Riley, Inc.)

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LATEST DEVELOPMENTS AND APPLICATION OF DB RILEY'S LOW NO_x CCV® BURNER TECHNOLOGY

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Craig A. Penterson, Manager, Fuel Equipment Design
and
Terence R. Ake, Staff Engineer
DB Riley, Inc., Worcester, MA

ABSTRACT

Recent developments in DB Riley low NO_x burner technology and the application of this technology in coal fired utility boilers are discussed. Since the promulgation of the Clean Air Act Amendment in 1990, DB Riley has sold nearly 1500 Controlled Combustion Venturi (CCV®) burners on pulverized coal fired utility boilers reducing NO_x emissions 50 - 70% from uncontrolled levels. This technology has been retrofitted on boiler designs ranging in size and type from 50 MW front wall fired boilers to 1300 MW opposed fired cell type boilers.

In DB Riley's latest version of the CCV® burner, a second controlled flow air zone was added to enhance NOx control capability. Other developments included improved burner air flow measurement accuracy and several mechanical design upgrades such as new coal spreader designs for 3 year wear life. Test results of the CCV® dual air zone burner in DB Riley's 100 million Btu/hr (29 MW) coal burner test facility are presented. In the test program, coals from four utility boiler sites were fired to provide a range of coal properties. A baseline high volatile bituminous coal was also fired to provide a comparison with 1992 test data for the CCV® single register burner. The test results showed that the second air zone enhanced NOx reduction capability by an additional 20% over the single register design. Computational fluid dynamic (CFD) modeling results of the CCV® dual air zone burner are also presented showing near field mixing patterns conducive to low NOx firing.

DB Riley was recently awarded Phase IV of the Low Emission Boiler System (LEBS) program by the U.S. Department of Energy to build a proof of concept facility representing the next major advancement in pulverized coal burning technology. A key part of winning that award were test results of the CCV® dual air zone burner with advanced air staging and coal reburning in a 100 million Btu/hr (29 MW) U-fired slagging combustor test facility. These results showed NOx emissions of less than 0.2 lb/million Btu (0.086 g/MJ) while converting the coal ash into an inert, non-leachable solid. This result is an 80% reduction in NOx emissions from currently operating U-fired slagging boilers.

INTRODUCTION

During the past seven years, most of the utility boiler business has focused on retrofitting units with low NO_x burners to meet Phases I and II of the 1990 Clean Air Act Amendment. Typically, boiler manufacturers are required to provide low NO_x burner technology for reducing NO_x emissions on coal fired units from pre-NSPS levels of 1.0 - 1.5 lb/10^6 Btu to <0.45 lb/10^6 Btu. These low levels of NO_x must be produced with minimal impact on boiler performance and operation. In addition, the burner components must last three years between major outages. Consequently, low NO_x burner technology must continually be updated, enhanced and improved upon to meet these strict demands[1].

This paper focuses on DB Riley's latest development efforts and design enhancements on our low NO_x Controlled Combustion Venturi (CCV®) burner technology for reducing NO_x emissions from coal fired utility boilers.

REVIEW OF CCV® BURNER TECHNOLOGY

DB Riley's CCV® burner relies on a unique patented (U.S. Patent No. 4,479,442) CCV® venturi nozzle technology which was developed in the early 1980's for reducing NO_x on coal fired utility boilers[2]. As shown in Figure 1, pulverized coal from the mills first enters the burner head which contains a multiple set of adjustable vanes that breakup any roping of the coal and produces a relatively uniform, homogeneous mixture at the exit of the burner head. As the coal mixture passes farther down the nozzle, the venturi section concentrates the coal in the center of the coal nozzle creating a fuel rich central core. This rich mixture finally passes over a low swirl coal spreader which divides the coal stream into distinct concentrated lobes or coal streams. These coal streams then enter the furnace in a gradual helical pattern, producing very gradual mixing of the coal and secondary air.

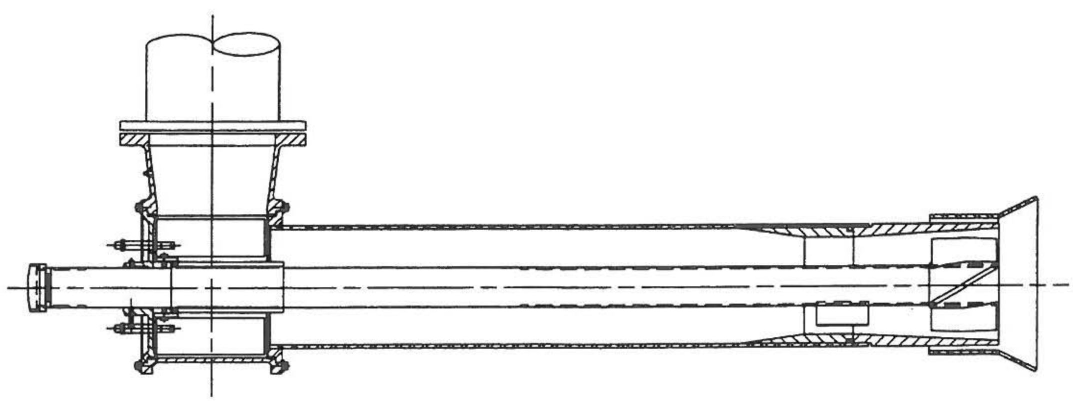

Figure 1 Controlled Combustion Venturi (CCV®) Coal Nozzle

The application of this unique nozzle design to our CCV® single register burner is shown in Figure 2. Secondary air initially passes through the air register to impart swirl and then through the burner barrel and over the secondary air diverter. Secondary air is then diverted away from the primary combustion zone, producing good separation between the primary and secondary air streams, thereby creating an area of recirculating hot combustion gases. This promotes stable ignition of the coal and well controlled flame attachment. Devolatilization of the coal in this fuel rich flame core occurs at the burner exit in an oxygen lean primary combustion zone, resulting in lower fuel NO_x conversion. Peak flame temperatures are also reduced, thus suppressing the thermal NO_x formation. The resulting coal flame is tubular in shape and firmly attached to the coal nozzle.

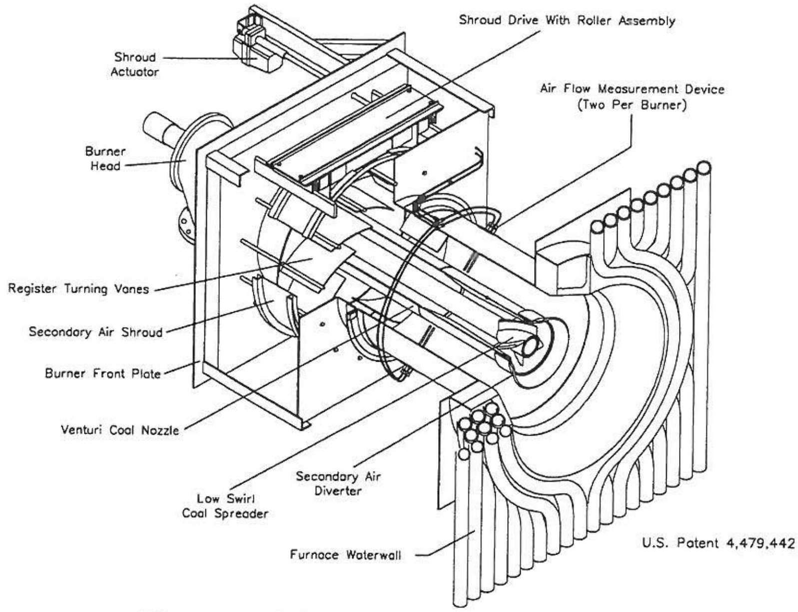

Figure 2 CCV® Single Register Burner

Computational fluid dynamic (CFD) modeling of the CCV® nozzle and burner was performed by Reaction Engineering International of Salt Lake City, Utah for DB Riley to closely study the effect of the venturi and coal spreader on the coal particle distribution and patterns leaving the nozzle. Figure 3 shows the particle mass density gradients for 60µm particle sizes of the venturi and coal spreader as viewed from inside the furnace. The smaller or tighter circles represent higher concentrations of coal. The distinct streams or lobes of coal are clearly evident with the venturi in place. Figure 4 again illustrates the concentrated lobes or coal streams at approximately two burner throat diameters downstream from the burner exit. The white and gray areas in the figure represent localized low levels of burner stoichiometry resulting from high concentrations of coal in these regions.

Figure 3 Particle mass density in the coal nozzle for a CCV® burner. (Reaction Engineering International)

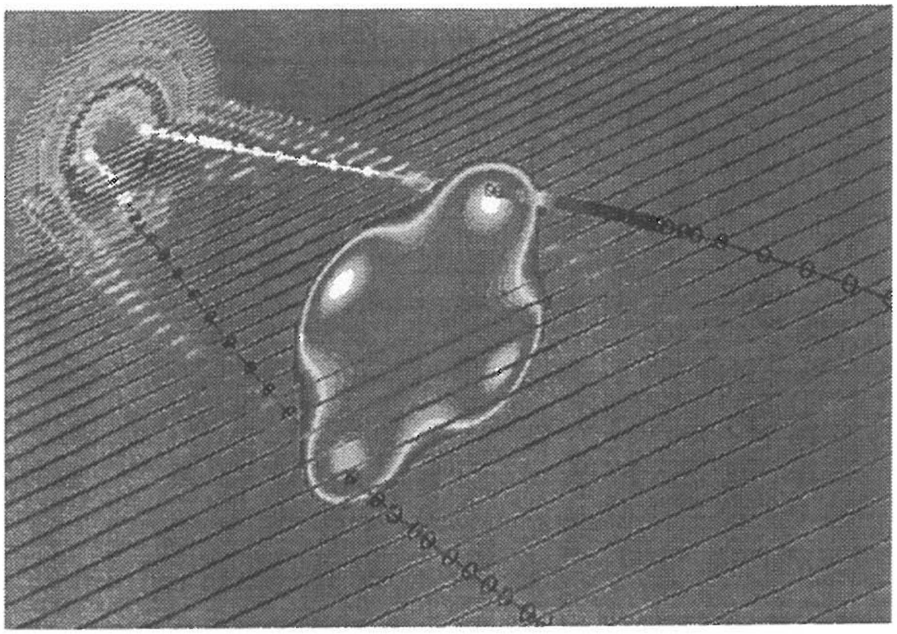

Figure 4 Near field stoichiometry at the CCV® burner nozzle exit (Reaction Engineering International)

DB Riley has retrofitted over 750 low NO_X CCV® burners in front, opposed and cell fired boiler designs[3]. Unit capacities have ranged from 50 to 1300 MW with some units equipped with over 100 burners each. The most challenging of these units for reducing NO_X emissions are cell fired boilers. These units typically exhibit extremely high heat release rates in the burner zone and produce high levels of uncontrolled NO_X emissions. Figure 5 shows the application of our CCV® technology in a cell burner configuration.

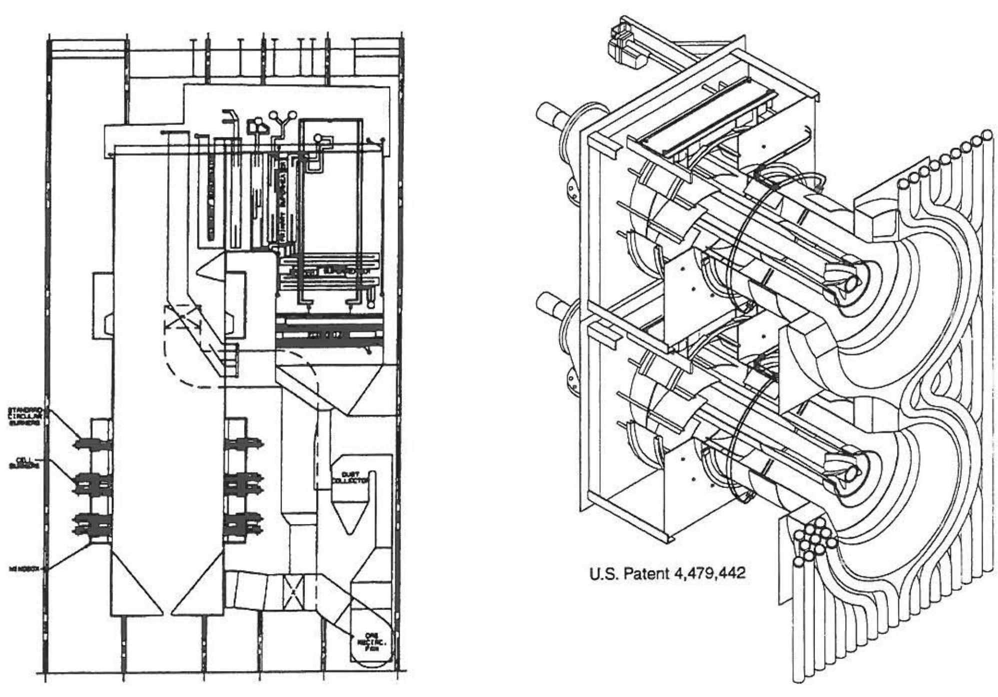

Figure 5 CCV® Cell Burner application

Some unique applications have involved only the installation of our patented CCV® coal nozzle design into existing burner hardware. One utility boiler retrofit was to correct a problem with high unburned carbon while operating at low NO_x levels[4]. Another was to sufficiently reduce NO_x emissions to allow the utility to early elect for Phase I NO_x compliance without incurring the high capital cost normally associated with complete burner replacement.

NO_x reductions of 50-60% from uncontrolled levels are typical for retrofitting a unit with CCV® burner technology. These levels have been attained without the requirement for overfire air. Reductions up to 70% have been achieved with burners and overfire air. Flyash unburned carbon (UBC) is site specific and dependent on a number of variables including furnace residence time, furnace geometry, fuel characteristics, coal particle size and distribution and the required NO_x emission level[5]. UBC levels have ranged from <1% on some units to >20% on others during low NO_x operation.

Current plans for DB Riley are to retrofit various coal fired utility boilers (front, opposed and cell fired) with another 750 low NO_x CCV® burners which will result in nearly 1500 CCV® burners being supplied to the utility industry for meeting phases I and II NO_x compliance.

CCV® BURNER DESIGN ENHANCEMENTS

Added Tertiary Air Zone

One of the major design enhancements incorporated a few years ago into our CCV® burner technology was the inclusion of an additional combustion air zone referred to as tertiary air. This dual air zone arrangement provides additional control of the burner zone stoichiometry at the coal nozzle discharge for further NO_x control. This is particularly beneficial on "burners only" applications to preclude the need for overfire air ports. As shown in Figure 6, the CCV® dual air zone burner provides independent control of secondary and tertiary air in two concentric passages surrounding the patented CCV® coal nozzle design which incorporates the same low swirl coal spreader design used in other CCV® burners. This dual air zone design provides DB Riley with another burner design option for reducing NO_x emissions from coal fired boilers.

The dual air zone CCV® burner along with the CCV® single register and CCV® cell burner designs provides DB Riley with a "family" of low NO_x burners to select from for a particular application. This wide range of burner options allows flexibility to chose a design that would be most suitable for a particular project, based on NO_x emission requirements, boiler configuration and budget constraints.

The secondary air inlet passage of the CCV® dual air zone burner contains adjustable secondary air dampers for controlling the flow split between secondary and tertiary air as well as the near field burner zone stoichiometry. A set of axial swirl vanes are used to impart the required degree of swirl necessary for good flame attachment and shape. Tertiary air flow is controlled by the burner air shroud while another set of axial swirl vanes in the tertiary air annulus controls the mixing of tertiary air into the combustion process.

Combustion Test Results

In 1996, a 100 million Btu/hr (29 MW) prototype of the CCV® dual air zone burner was tested at the DB Riley Research Center in Worcester Massachusetts. The DB Riley Research Combustion Test Facility, shown in Figure 7, can test a single full-scale burner for a wide

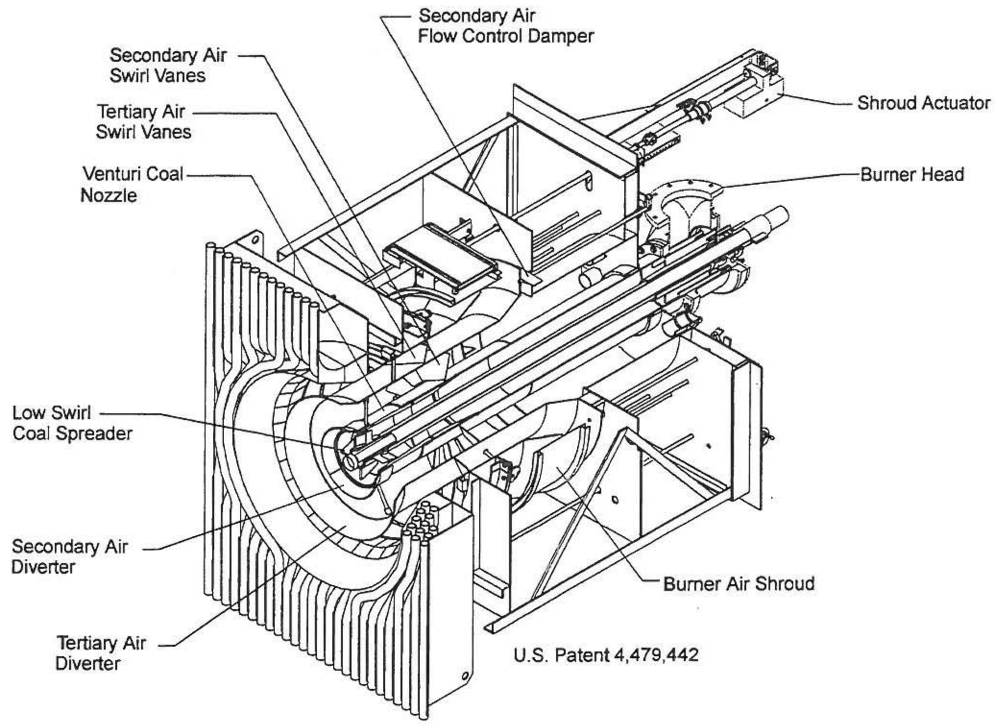

Figure 6 CCV® Dual Air Zone Burner

Figure 7 Aerial view of the Combustion Test Facility at DB Riley Research in Worcester, Massachusetts

range of firing conditions[6]. This test facility has been used for over twenty years to test and develop not only DB Riley burner technology, but also burner technology from several domestic and international manufacturers.

Five coals were fired in the test program providing a wide range of coal properties. Table 1 lists the coal property values for each coal. The high volatile Pennsylvania coal served as a baseline for comparing the CCV® dual air zone burner results with the results from a 1992 DB Riley Research test program of the CCV® single register burner firing Pennsylvania coal. The other coals were from four utility boiler sites representing potential retrofit applications.

Figure 8 shows a comparison of the NO_X emissions for the CCV® dual air zone burner with the CCV® single register burner firing Pennsylvania coal at 100 million Btu/hr (29 MW). We found that the NO_X emissions for the dual air zone burner were over 20% lower than the single register burner. As can be seen in the figure, the NO_X levels for the dual air

Table 1 CCV® Dual Air Zone Burner Test Coals

Origin	West Virginia	Pennsylvania	Alabama	Eastern Kentucky	South America
Dry Proximate Analysis:					
Volatile Matter (VM), Percent	35.2	36.2	25.9	35.9	38.7
Fixed Carbon (FC), Percent	51.2	53.6	61.4	48.8	56.4
Ash, Percent	13.6	10.2	12.7	15.3	4.9
FC/VM Ratio	1.46	1.48	2.37	1.36	1.45
FC/VM x Ash, Percent	19.8	15.1	30.1	20.8	7.1
Higher Heating Value, Btu/lb	12665	13487	13515	12869	14142
Lower Heating Value, kJ/kg	28208	30146	30248	28584	31531
Hardgrove Grindability	36	55	79	44	43

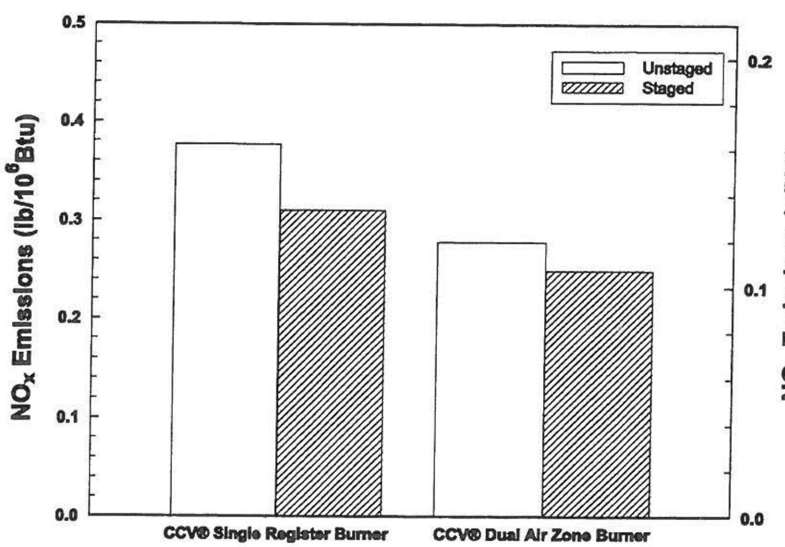

Figure 8 NO_X emissions for the CCV® Single Register Burner compared to the CCV® Dual Air Zone Burner firing Pennsylvania coal at 100 million Btu/hr (29 MW) zone burner were comparable to the single register design with moderate amounts of overfire air. Overfire air was also tested while firing with the dual air zone burner. However, it did not provide as much NO_X reduction as when overfire air was applied to the single register burner. This result demonstrates that the NO_X reduction potential for various combustion controlled technologies is not cumulative.

The low level of NO_X for the CCV® dual air zone burner was achieved on all of the test coals by optimizing the axial swirl vane settings in the secondary and tertiary air passages and the secondary to tertiary air flow ratio. Figure 9, for example, shows the effect of secondary air swirl on NO_X emissions firing the West Virginia coal. When firing the other coals, the same secondary air swirl effect on NO_X emissions was observed. Tertiary air swirl also had a strong effect on NO_X emissions, but the effect depended upon coal type. Minimum NO_X emissions at the same air flow ratio for each coal was also observed.

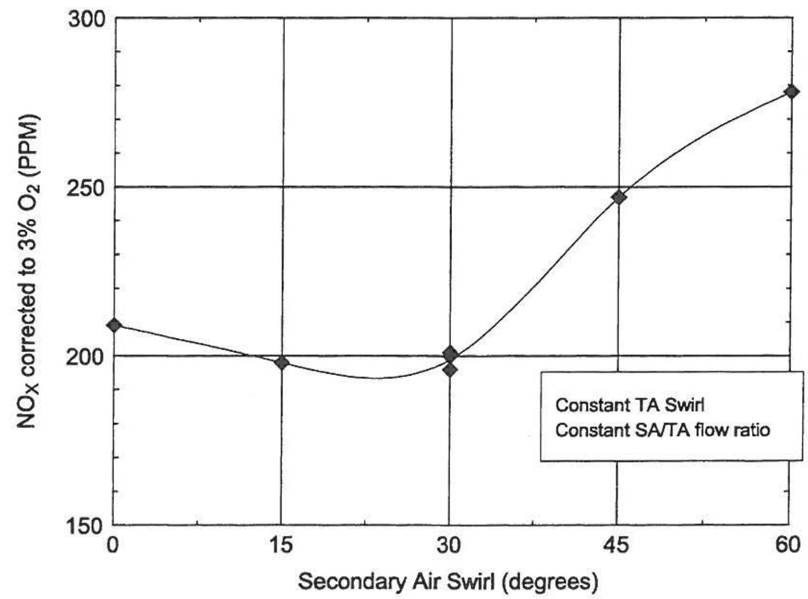

Figure 9 The effect of secondary air swirl on NO_X emissions for the CCV® Dual Air Zone Burner firing West Virginia Coal at 100 million Btu/hr (29 MW)

CFD Modeling Results

CFD modeling of the CCV® dual air zone burner, designed for a new 150 MW coal fired utility boiler, was performed by DB Riley using Fluent to study the near field mixing patterns at the burner discharge. Figures 10 and 11 show results of performing a two- dimensional axisymmetric aerodynamic analysis of velocity magnitude and velocity vectors, respectively. The results indicate excellent separation in the near field region between the primary air/coal stream and secondary/tertiary air streams for efficient NO_X control. Strong recirculation or reverse flow also occurs in this separation zone to promote good flame attachment. This is imperative for proper low NO_X operation.

Burner Air Flow Measurement

Accurate measurement of combustion air flow on a per burner basis in a multiple burner/common windbox design has, up to now, been extremely difficult. This is due to the highly turbulent, swirling, non-uniform flow field produced in the burner annulus or annuli surrounding the coal nozzle where air flow probes are typically installed.

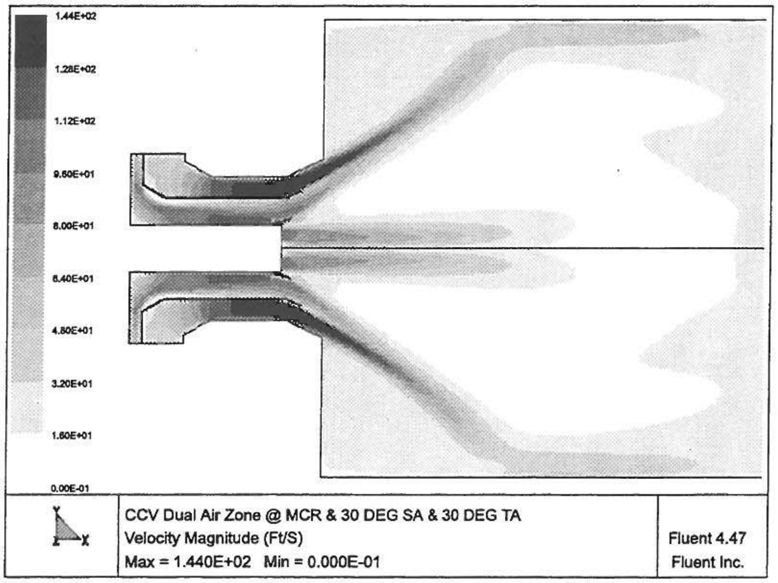

Figure 10 Velocity magnitude of a CCV® Dual Air Zone Burner (Analysis by DB Riley)

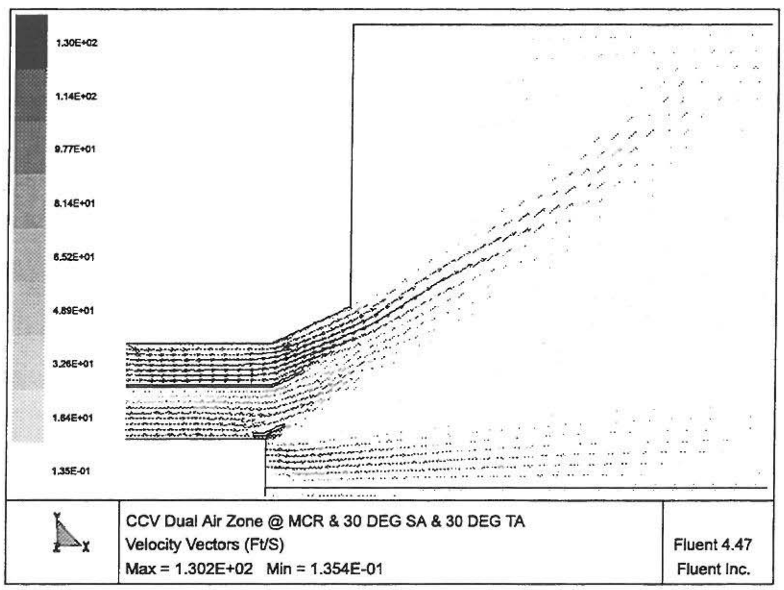

Figure 11 Velocity vectors of a CCV® Dual Air Zone Burner (Analysis by DB Riley)

To improve the accuracy of this air flow measurement, DB Riley, in cooperation with Air Monitor Corporation (AMC) of Santa Rosa, California and a large midwest utility company, have developed specially designed air flow or IBAM™ (Individual Burner Air Measurement) probes for application to our CCV® burner technology including single register, cell and dual air zone designs. The basic probe design is based on AMC's multiple point, self averaging pitot tube[7] or Volu-Probe ® (U.S. Patent 4,559,835). These probes, specially designed for our CCV® burners, are strategically located in the burner annulus depending on swirl direction, placement of ignitor and scanner sight tubes and any other flow obstructions that may exist. Figure 2 (on page 4) shows the application of these probes to a single register

CCV® burner design. Extensive testing was performed in AMC's wind tunnel facility in Santa Rosa on a full scale single register CCV® burner to calibrate the IBAM probes for various burner register and shroud settings. The results indicated the variance or error in the IBAM flow measurement, when compared to the flow measured using an ASME nozzle, typically varied from -1% to +13% for the complete range of burner settings tested. The error averaged only +5% to +10% for "normal" burner settings. The data was also found to be very repeatable. The unique IBAM probes provided by Air Monitor Corporation have been adopted as DB Riley's standard method of flow measurement on all low NO_x CCV® burner designs.

This significant enhancement to our CCV® burner designs will provide improved capability for accurately controlling secondary air flow to each burner and for optimizing the burner operation to achieve the lowest possible NO_x emissions and unburned carbon in the flyash.

Mechanical Design Upgrades

To meet the requirement of being able to operate low NO_x burners maintenance free for a minimum of three years between major plant outages, DB Riley has focused significant development effort on the low swirl coal spreaders. The coal spreader has been the only burner component that has not typically survived three years of continuous operation. Development efforts have concentrated on evaluating better wear and temperature resistant materials as well as modifying the design. Test materials have included special metal alloys and ceramics while the design was upgraded from being fabricated to a casting to eliminate critical weld cracking sometimes experienced in the past due to high thermal stresses.

Testing of new materials and designs is currently ongoing in 600 MW and 1300 MW utility boilers. These boilers were selected as suitable host sites since they exhibit high heat release rates and typically operate at full load with burners out of service. This mode of operation exposes the coal spreaders to very high temperatures and thermal stresses. Preliminary results look encouraging for one of the cast metal alloys and also for the ceramic material.

Another mechanical design enhancement or upgrade incorporated into our CCV® burner designs involved a redesign of the support leg system used to support the secondary and tertiary air diverters within the burner barrel. The support legs, attached to the diverters, are inserted into pipe sleeves welded to the burner barrel. Two of these legs are welded to the sleeves while the other leg is not welded and free to move in and out of the pipe sleeve as the burner barrel expands and contracts. This enhances weld reliability and eliminates barrel distortion. The mechanical integrity of the diverter has also been upgraded to increase the strength of the weld between the conical and cylindrical sections. This eliminates cracking of this critical weld from high thermal stresses which occur when burners are removed from service.

The burner heads have also been redesigned to have flanged connections with gaskets where the CCV® coal nozzle connects to the burner head. The nozzle is now fixed and non-adjustable based on data from numerous low NO_x installations. This eliminates the potential for coal leaks. Previous designs utilized an adjustable coal nozzle sliding inside a bushing which was prone to coal leaks over time. The protective sleeve surrounding the coal spreader support tube inside the burner head was upgraded from mild carbon steel to an abrasion resistant cast alloy material. The wear life has greatly improved.

All of the mechanical design upgrades discussed have been applied to all CCV® burner designs.

APPLICATION OF CCV® BURNER TECHNOLOGY TO LEBS PROJECT

The CCV® dual air zone burner is now being applied in the Low Emission Boiler System (LEBS) program for the U. S. Department of Energy (DOE)[8]. The objective of the program is to develop a new generation of coal-fired boiler design which will meet emission limits of 0.1 lb/10^6 Btu (0.043 g/MJ) of NO_x, 0.1 lb/10^6 Btu (0.043 g/MJ) of SO_2, and 0.01lb/10^6 Btu (0.0043 g/MJ) of particulate. Additional objectives include improved ash disposability, reduced waste generation, reduced toxic substance emission, and increased efficiency, with a goal of approaching or exceeding 42% net plant efficiency (HHV basis).

The U.S. DOE has awarded Phase IV of the LEBS program to the DB Riley project team which includes Sargent & Lundy LLC, Thermo-Power Corporation, the University of Utah, and Reaction Engineering International. In Phase IV, the project team will develop a system which includes a low-NO_x slag tap firing furnace, a supercritical boiler, a regenerable desulfurization system with de-NO_x capability, and advanced heat recovery and particulate removal systems. The project team will build a Proof of Concept facility between 40 MW and 80 MW in electric generation output to demonstrate key components of the Low Emission Boiler System.

The CCV® dual air zone burner was tested in a 100 million Btu/hr (29 MW) thermal input U-fired slagging test facility shown in Figure 12. This facility used the infrastructure of the existing combustion test facility at DB Riley Research for fuel and air flow input and flue gas treatment.

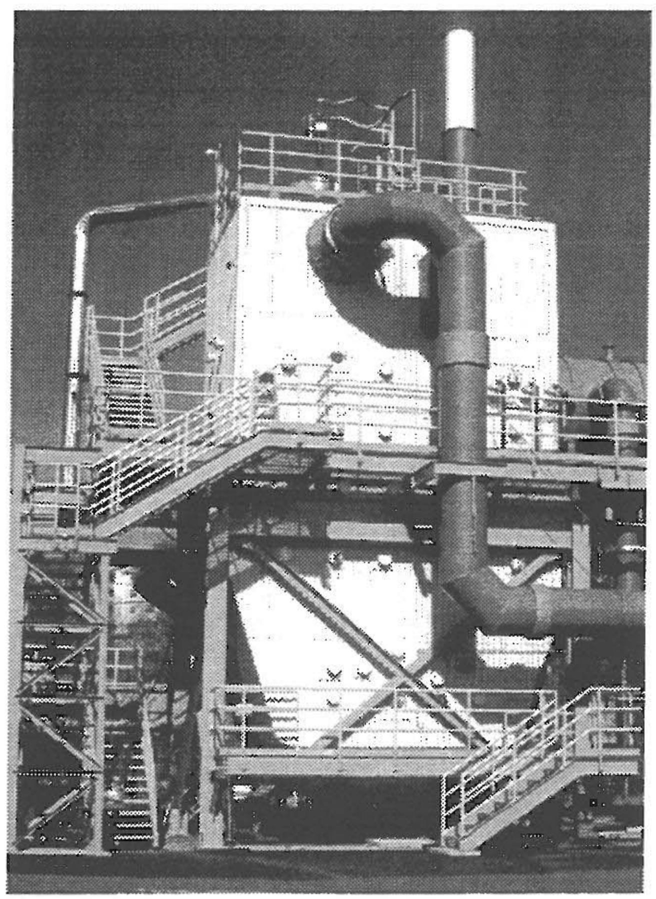

Figure 12 The U-fired test furnace at DB Riley Research

A high sulfur, midwestern coal and a medium sulfur, eastern coal fired in the test facility produced similar results. The test results are summarized in Figure 13 for the medium sulfur eastern coal. We tested a baseline burner simulating burners in a commercially operating U-fired slagging boiler to validate the test facility results. The baseline burner produced similar NO_x emissions as the commercial boiler. When the CCV® dual air zone burner alone was tested, it gave dramatically lower NO_x emissions than the baseline burner; nearly 60% lower. When advanced air staging and coal reburning were applied, NO_x emissions were below the goal for the combustion system of 0.2 lb/10^6 Btu (0.086 g/MJ). This NO_x emission was 80% lower than the baseline burner. These results were obtained while converting the coal ash into an inert, non-leachable solid at high furnace temperatures. The carbon in the slag averaged less than 1%. Since most of the coal ash was converted to slag, the overall carbon loss was small (1% to 2% on a heat loss basis).

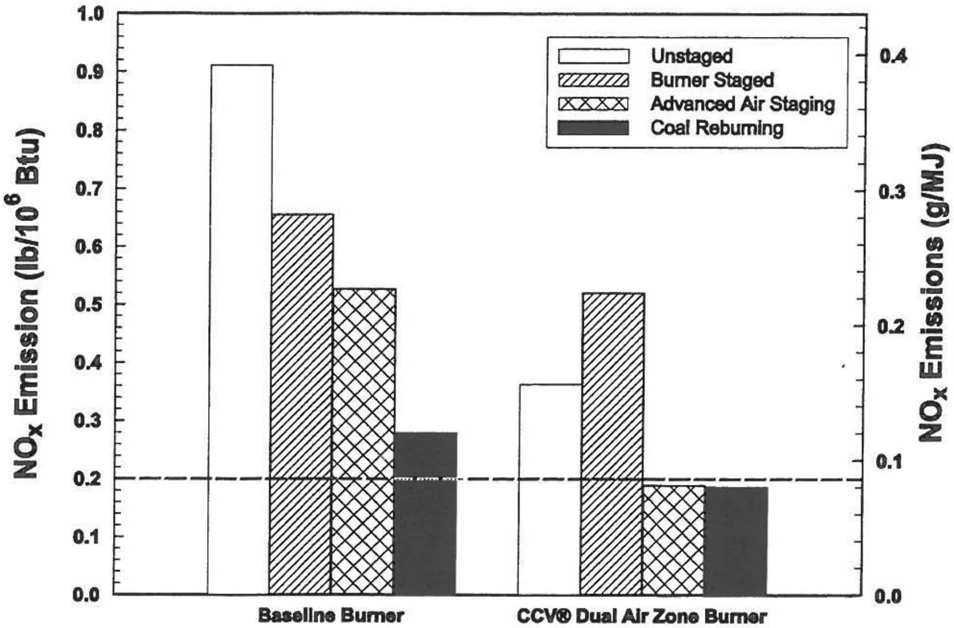

Figure 13 U-fired test furnace NO_x emissions firing a medium sulfur eastern coal at 100 million Btu/hr (29 MW)

These results showed that a slagging firing system consisting of a low NO_x burner with either air staging or coal reburning and a regenerable desulfurization system with de-NO_x capability can meet the LEBS program emission goals. Further test results are provided in a companion paper presented at this conference[9].

SUMMARY

In response to Phases I and II of the 1990 Clean Air Act Amendment, DB Riley has and will be supplying nearly 1500 CCV® burners for reducing NO_x emissions 50 - 70% from coal fired utility boilers. The CCV® burner technology utilizes a unique patented venturi nozzle design for producing a fuel rich flame core, conditions necessary for low NOx. Recent enhancements to the CCV® burner technology have focused on an additional secondary air zone for 20% lower NO_x emissions, improved air flow measurement accuracy and several mechanical design upgrades in an effort to achieve 3 years of continuous maintenance free operation.

Several versions of the basic CCV® burner technology are available for reducing NO_x emissions. These include CCV® single register, CCV® dual air zone and CCV® cell type burner designs. This wide range of designs allows flexibility in selecting the design most suitable for a particular application, based on NO_x emission reduction requirements, boiler configuration, and budget constraints.

The key element in the DOE Proof of Concept LEBS Project Phase IV is the CCV® dual air zone burner design. Combustion testing of this design in a 100 million Btu/hr U-fired test facility produced dramatically low levels of NO_x despite the relatively high furnace heat release rates necessary for molten slag to form on the walls. Combining the low NO_x CCV® burner with advanced air staging and coal reburning produced NO_x emission levels well below 0.2 lb/10^6 Btu (0.086 g/MJ).

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