Lower NOx / Higher Efficiency Combustion Systems

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ABSTRACT

Advanced low NOx burners are demonstrating significant improvements in performance beyond first generation low NOx burner results. These burners plug in to existing burner openings, facilitating use and reducing expense and outage time. Multi-air zone OFA systems, optimized with computer modeling, enable further emission reductions. Results are presented showing 30 to 50% NOx reduction relative to high-quality first generation LNBs. This represents over 80% NOx reduction relative to uncontrolled sources with conventional burners. Unburned combustibles tend to increase with combustion modifications which reduce NOx. However, the new systems minimize this problem, without resorting to pulverizer upgrades. When pulverizer upgrades were simultaneously implemented, unburned combustibles were cut 80% along with major NOx reductions. Results are presented for 600 MW class units, substantiating the performance for a variety of coals, and verifying previous large-scale development work.

INTRODUCTION

The electric utility industry appears to be on the threshold of major changes as a result of the energy outlook in the United States. There is growing recognition that regional electricity shortages are symptomatic of a national energy imbalance in supply and demand. Additions to U.S. electric supply over the past decade have been almost exclusively provided by gas turbines. Rapid increases in natural gas consumption by these facilities have added strain to gas availability and contributed to dramatic price spikes during winter 2000/2001. There is no reserve capacity for gasoline production; gasoline prices are up, and expected to go higher. U.S. coal reserves are plentiful, but rail transport is near capacity for cleaner burning Powder River Basin (PRB) coal.

The new administration is making national energy policy a top priority. The economy depends on safe, reliable energy at a reasonable cost. A well-designed policy will promote electrical power generation additions from various sources to ensure supply reliability, while encouraging conservation measures. Coal, a dirty word for the last decade, is once again receiving serious attention. Nuclear power may be an option. Obviously some changes are needed, and certainly changes will occur—but not necessarily for the best. A well thought out energy policy is fundamental to directing changes in a way that makes sense in the long run.

Setting aside political and economic forces, and emotions, what is the state of technology for coal as a player in new electrical generation? Pulverized coal (PC) fired power plants demonstrate high reliability and availability, and are much cleaner than ever before. Emissions of NOx, SO_2, and particulate are reduced by over 90% on many older plants relative to uncontrolled levels. This is accomplished by cleaner burning coal, advanced combustion systems, and backend clean up systems. New coal fired plants will no doubt achieve even better results. This paper considers the capability of B&W's advanced PC-fired low NOx combustion systems, as a key element in the efficient control of emissions from new or existing power plants.

B&W LOW NOx SYSTEMS

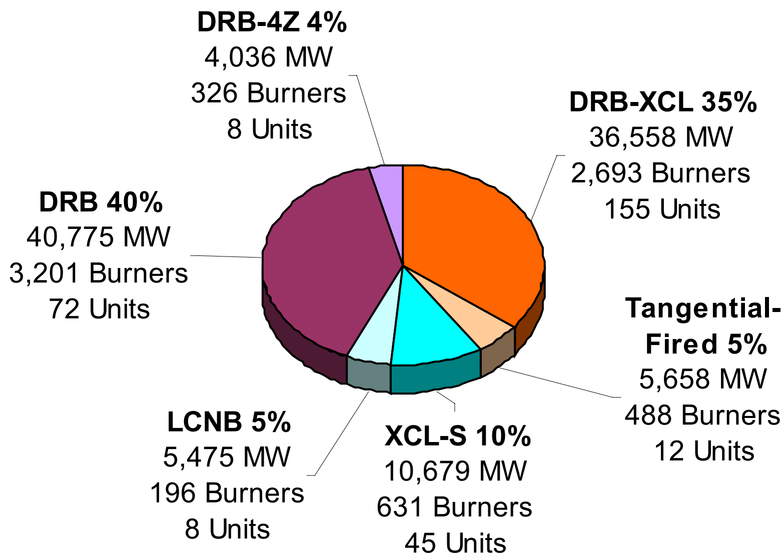
Regardless of the pace of new coal-fired generation growth in the US, emissions will be forced to lower levels for both new and existing plants. NOx is formed during the combustion of fossil fuels and has been said to contribute to ozone formation, visibility degradation, and human health concerns. Without emission controls, NOx may exceed 1000 ppm from a boiler, or 0.1% of the outlet gases. NOx formation can be limited by modifications to the combustion process and by changing fuel. Once formed, NOx can be reduced by injecting reagents in the furnace, or downstream of the boiler with Selective Catalytic Reduction (SCR) systems. SCR is required to accomplish the lowest levels of NOx. However, it is usually more cost effective to limit NOx as much as possible with the combustion system, then achieve the remaining reduction by SCR. Combined use of combustion modifications and SCR can reduce NOx to less than 50 ppm (0.005%).

B&W has developed a wide range of combustion systems to reduce NOx emissions from power plants. Investigations began over 40 years ago with pioneering work in the use of air staging systems. The company's first generation low NOx coal burner, the original Dual Register Burner® (DRB), was developed 30 years ago. Since that time B&W has amassed over 100,000 MW of capacity with B&W low NOx burner systems (Figure 1), plus another 7,000 MW of low NOx systems for cyclone fired boilers.

Most of the low NOx systems are installed on PC-fired boilers. This began with DRBs installed as original equipment in power plants built during a period of rapid expansion in the 1970s and 80s. These were installed on 72 units totaling about 41,000 MW. More recently, low NOx systems have been retrofitted to boilers built by other suppliers as well as B&W. In some cases the new systems replace conventional equipment which was not designed to control NOx, and in other cases they replace first generation equipment with more advanced low NOx systems. These retrofits, primarily over the past ten years, now equal capacity of the original equipment low NOx applications.

The experience reflected in Figure 1 amounts to 300 units and totals over 7,500 burners. The units range from single-wall fired units as small as 20 MW with 4 burners, up to opposed-fired units as large as 1300 MW with 98 burners. It includes one-wall, two-wall and four-wall fired units- roof-fired units, and corner-fired units. Coals range from Texas lignite with 5,000 Btu/lb to medium volatile bituminous coals from South Africa and Australia. This experience is a consequence of continued improvements in technology and equipment design, resulting in systems which lead the industry in emission control.

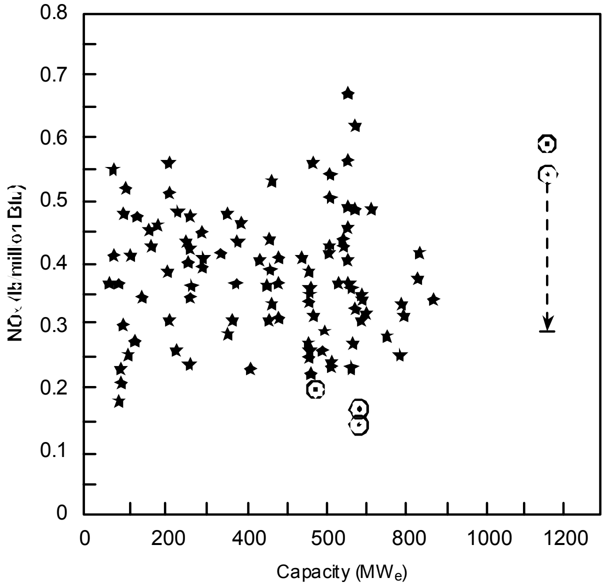
Figure 1: B&W Low NOx Combustion Equipment Summary – All Fuels



Emissions results for some of the wall-fired units (coal) are summarized in Figure 2. The graph displays EPA Continuous Emission Monitor (CEM) published NOx data, or full load test data when available, for over 100 units. This displays units for which data was readily available. It includes units with first generation DRBs installed in the 70s when the NOx emission limit was 0.70 lb/MBtu, and extends to retrofits commissioned in 2000. All of the units are at or lower than their original NOx guarantee level. Note several of the units achieve NOx emissions in the 0.15 to 0.20 lb/MBtu range. These are air-staged systems equipped with advanced low NOx burners firing subbituminous coal (some of which are discussed later in this paper). Also note some interesting results recently reported by a customer with a unit operating at 1160 MW. The combination of DRB-XCL® burners, Dual Zone NOx ports, and selective burners-out-of- service (BOOS) reduced NOx to 0.30 lb/MBtu while holding unburned carbon to 3 to 4% firing bituminous coal. The right hand portion of Figure 2 summarizes data by fuel and combustion system type. This shows the advantages of more reactive coals like subbituminous for NOx control, and the added advantages of air staging with low NOx burners.

Over the past two years B&W has been successful in providing low NOx solutions to tangentially-fired boilers. The B&W system includes overfire air (OFA) located above the main combustion zone (Figure 3). OFA has been shown to be the most effective technique in reducing emissions from these units and B&W's approach has been to install the OFA system either at the corners (tangential injection) or on the front and rear walls ("interlaced" injection). The actual injection location depends on the furnace aerodynamics, unit arrangement and space available. Over the past years B&W has been awarded low NOx conversions for 12 units representing over 5,600 MW. Results from some of the units in operation indicate NOx emission levels achieved in the order of 0.25 lb/MBtu or less depending on the type of coal fired.

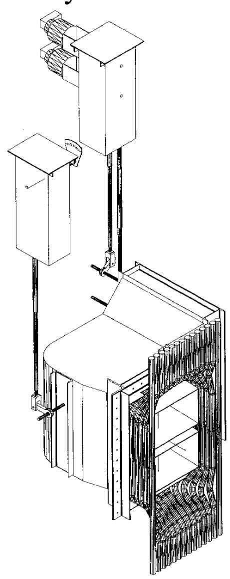
Figure 2: B&W Low NOx Combustion systems



B&W Low NOx Combustion Systems--NOx Emissions
Wall Fired and Pulverized Coal
(EPA-CEM data or full load test data when available)
Burners Installed 1975 to 1999

NOx Emissions (lb/million Btu)	Units	Characteristics
>0.50	12	Bituminous or medium volatile bituminous
0.40 - 0.499	39	Bituminous
0.30 - 0.399	36	Subbituminous/lignite or staged bituminous
0.20 - 0.299	24	Subbituminous/lignite or staged bituminous
0.10 - 0.199	4	Staged subbituminous

Figure 3: B&W Low NOx Systems for Tangentially-Fired Boilers



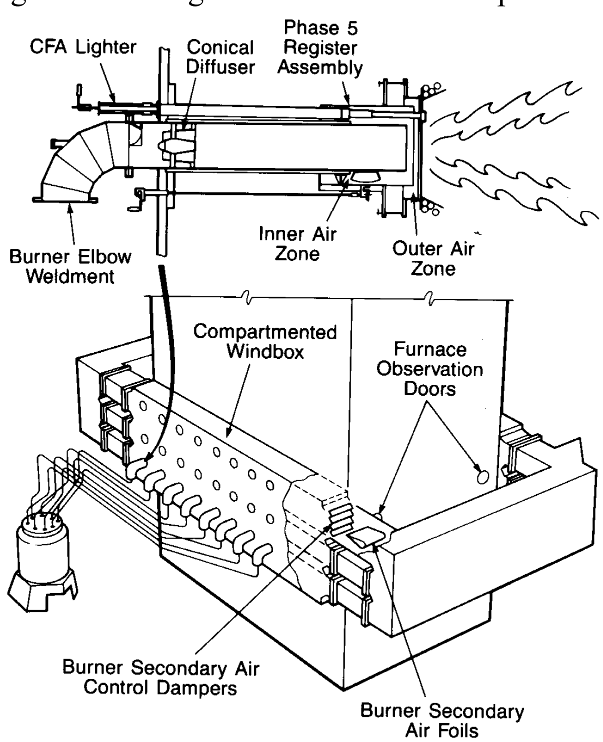
First Generation Low NOx Combustion Systems

NOx is formed during the combustion of coal primarily by two mechanisms. Thermal NOx is a consequence of oxidation of nitrogen in air, and fuel NOx results from oxidation of nitrogen in the coal. Thermal NOx increases exponentially with temperature, and control is accomplished by moderating flame temperature and oxygen concentration. Fuel NOx forms as nitrogen in the hydrocarbon fuel matrix oxidizes, and is controlled by limiting oxygen availability during the combustion process, particularly in the early stages. Techniques which reduce oxygen availability as the flame forms can effectively reduce NOx, but tend to increase unburned combustibles (CO and/or carbon particulate). Higher unburned combustibles tend to occur even if the total air introduced to the process is the same. This can be due to incomplete mixing of air and fuel, or due to insufficient residence time to complete combustion after the air is completely introduced.

Many first generation low NOx systems for PC-fired boilers relied on conventional burner designs which were supplemented with air staging systems. The conventional single air zone burners provided minimal NOx reduction in and of themselves. The flaw of single air zone designs for NOx control is the simultaneous requirement of flame stabilization. Circular PC-fired burners are catagorized as swirl-stabilized, meaning swirl imparted to the secondary air generates the necessary recirculation in the flame to anchor and stabilize the ignition point at the burner. As swirl is reduced, flame stability is lost. However, swirl also causes more rapid air mixing with the fuel tending to increase NOx. To compensate for shortcomings of single air zone burners, air is removed from the burner and returned later in the combustion process (air staging). This can be done through idle burners (BOOS) or through air ports dedicated to this purpose, referred to as NOx ports or OFA ports.

In contrast to this approach, B&W's first generation low NOx system was based on a dual air zone burner. This approach was unique at the time, but now is nearly universal for low NOx burners. In the Dual Register Burner (DRB), secondary air to each burner is divided into two air streams which concentrically surround the axial fuel nozzle (Figure 4). The stream closest to the coal nozzle, or inner air, is swirled to a higher rate to provide the necessary flame stabilizing function. But this stabilizing inner air is just a fraction of the secondary air so NOx formation is

Figure 4: Original Dual Register Burner With Compartmented Windbox



limited. Secondary air supplied in the outer annulus, or outer air, is moderately swirled and gradually introduced to the flame to complete combustion. These DRBs proved capable of 40 to 50% NOx reduction and were able to meet applicable Federal NOx standards without resorting to BOOS or NOx ports. Data shows that dual air zone burners are much more effective for NOx control when compared to a single air zone burner.

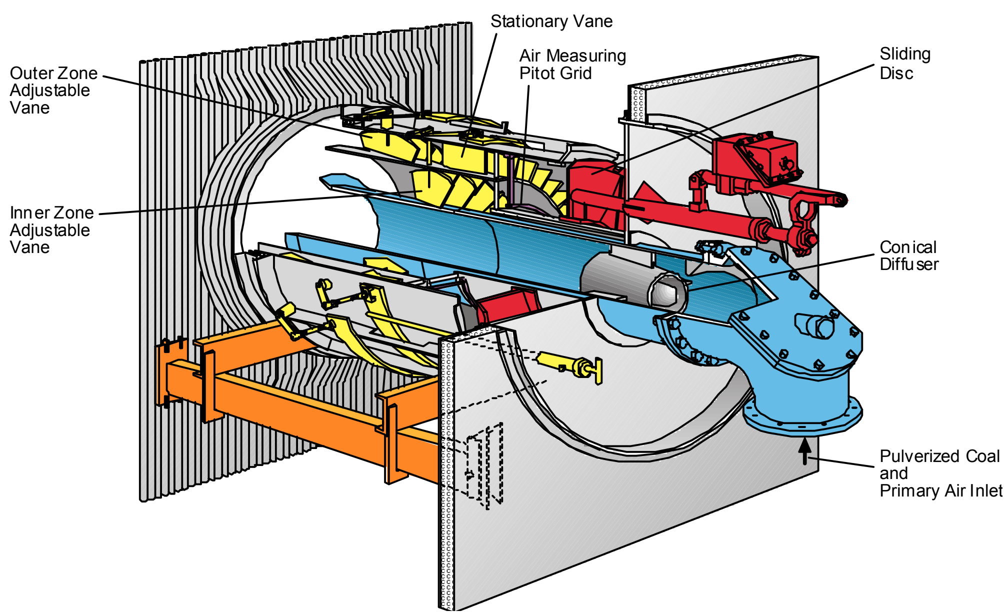
Advanced Low NOx Combustion Systems

The DRB earned a good reputation for effective NOx control with various U.S. coals, over the full range of utility boiler sizes. However, some advancements to the DRB were required to optimize its use for existing and new boilers. The burner was designed for use in new boilers equipped with compartmented windboxes. This relegated control of secondary air flow quantity to compartment dampers, which worked well in this regard. However, the burner hardware arrangement required some refinements to be better suited for retrofit to existing boilers.

B&W developed its second generation low NOx burner, the DRB-XCL® burner, in the mid-late 80s to address NOx control needs for existing (and new) boilers. Existing units not equipped with low NOx burners were facing NOx control regulations. These units needed an effective, rugged design that was adaptable to the diverse population of B&W boilers and those of other suppliers. The development and results with the DRB-XCL burner have been well documented elsewhere and are only briefly considered here.

The DRB-XCL burner (Figure 5) shares the dual air zone philosophy of the original DRB but in a largely reconfigured arrangement. The most obvious commonality is with the axial burner nozzle. The nozzle could be equipped with the patented conical diffuser/deflector for lowest

Figure 5: PC-Fired Low NOx DRB-XCL Burner

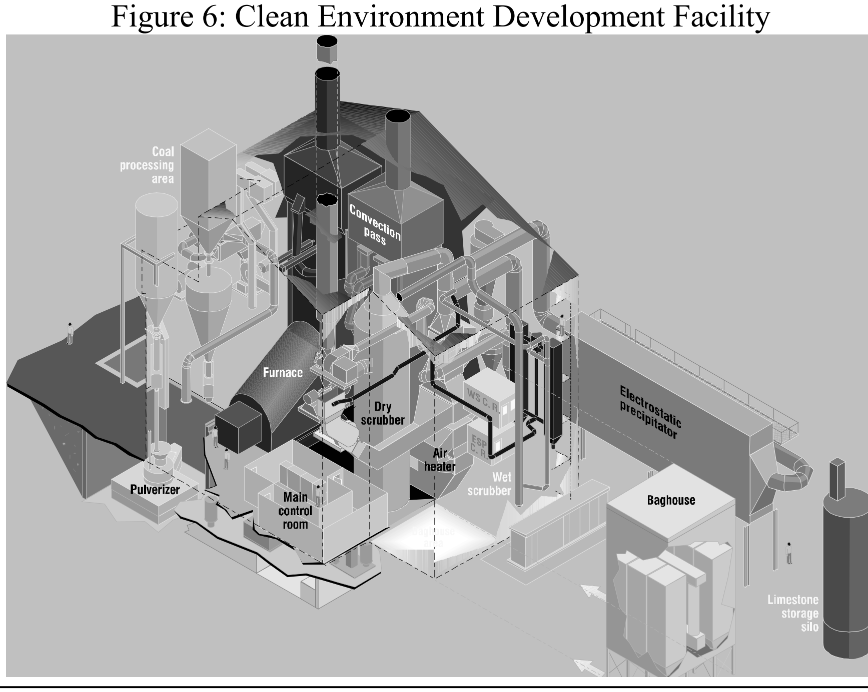


NOx (like the DRB), or with bladed impellers to shorten the flame and reduce unburned carbon. Secondary air flow is controlled to each burner with a reliable sliding air damper. In open windbox applications, the damper is automated with a linear actuator to regulate secondary air as necessary. Settings are established for cooling out-of-service burners, for initial light-off, and for normal operation. A pitot grid is provided to indicate relative air flow into the burner, for use in commissioning adjustments. Multi-point air flow measurement with the pitot grid provides a more representative indication of air flow than single point measurement, given the variation of inlet flow conditions to burners. The inner and outer air zones are equipped with adjustable vanes which are set during commissioning to optimize emissions. The vane control mechanisms were completely redesigned and provide reliable adjustment.

The DRB-XCL burner was selected by utilities for over 150 units to meet their NOx reduction needs. These include small single-wall-fired units with burners rated at 50 MBtu/hr, as well as large opposed-fired units with burner inputs of 300 MBtu/hr. NOx emissions with the DRB-XCL burner are about 20% lower than the original DRB, providing up to 60% reduction from uncontrolled levels. Actual emissions depend on the coal and furnace design. Further NOx reduction is accomplished by adding NOx ports. The DRB-XCL has proven to be rugged and reliable in these challenging circumstances.

The growing need for advanced combustion and gas clean-up equipment to serve the utility industry led B&W to construct the Clean Environment Development Facility (CEDF) at the MTI Research Center in Alliance, Ohio. This state-of-the-art facility (Figure 6) was designed and constructed in the early 90s and serves as the cornerstone for B&W's burner development work. Proprietary numerical models and small scale combustion facilities complement the development efforts. The CEDF enables near full scale evaluation of burner prototypes, with inputs up to 100 MBtu/hr. Initial test programs in the CEDF were used to baseline emission performance with the DRB-XCL for a variety of coals.

Figure 6: Clean Environment Development Facility



Development resources were then directed at further improving emission performance and versatility of low NOx coal-fired burners. This involved not only further NOx reduction advancements, but burners which simultaneously improved combustion efficiency.

LOW UNBURNED COMBUSTIBLES WITH LOW NOx

Additional development work was recently completed to further improve the versatility and emission performance of the DRB-XCL® burner. One goal was to adapt the XCL burner for "plug-in" use on existing boilers without requiring pressure part modifications. This reduces equipment costs for retrofits, and shortens outage time for installation. Simultaneously, the program was directed at further emissions reductions. NOx performance for the XCL was actually very good, but unburned carbon emissions were sometimes high. Unburned carbon depends not only on burner design, but excess air, coal properties, fineness, furnace arrangement, and operational practices. The goal was to reduce unburned carbon without impairing NOx performance. This is quite challenging as there is a strong, natural tendency for NOx to increase as unburned carbon is reduced (all other conditions held constant).

Initial tests with the reduced (test) sized XCL produced higher NOx and unburned carbon emissions. The goals were ultimately achieved in the lab by reconfiguring the air zones, the front end hardware for the air zones, and front end burner nozzle hardware. Large-scale burner tests enabled fine tuning of the hardware to optimize performance.

The first commercial application of the plug-in DRB-XCL burner was in a 300 MW class, opposed-fired unit. The unit was equipped with two elevations of two-nozzle cell burners, forming a hot compact burner zone less than 16 ft. tall. The unit fired a blend of eastern bituminous coals (FC/VM 1.4-1.5). Pre-retrofit emissions were 1.0 lb/MBtu NOx with 1 – 1.5% unburned carbon (UBC). Coal fineness was somewhat low with 58% minus 200 mesh. The cell burners were simply replaced with plug-in DRB-XCL burners along with new lighters and flame scanners. OFA and mill upgrades were not used. Post-retrofit results at full load are typically 0.45 to 0.50 lb/MBtu NOx with 1 to 2% UBC (Figure 7). This is considered excellent combined NOx/UBC.

The above retrofit accomplished significant NOx reductions with low UBC by virtue of burner design. Another means to this end is to combine pulverizer upgrades to increase fineness, in combination with an effective low NOx combustion system. An illustration was a two-step project on a 600 MW class unit originally equipped with cell burners. The unit fires bituminous coal with FC/VM of ~1.3 and 12% ash. Baseline emission tests indicated full load NOx of 1.4 / 1.1 lb/MBtu with UBC of 1.6 / 3.7% for all mills / one mill out conditions (Figures 8 and 9). The furnace wall panels needed replaced on the front and rear wall and it was decided to simultaneously revise the combustion system. The burner quantity was reduced from 48 to 36, and rearranged for level firing (one mill serving each row of six burners). Standard DRB-XCL burners were used in combination with Dual Air Zone NOx ports. The new system reduced NOx by 65 to 75%, down to 0.3 to 0.4 lb/MBtu. But UBC increased to 4 to 8%, depending on burner zone stoichiometry. Coal fineness was somewhat low, with 55% minus 200 mesh/ 90.4 minus 100 mesh, and 99.8% minus 50 mesh.

Figure 7: 300 MW Unit With Cell Burners Retrofitted With Plug-In DRB-XCL Burners

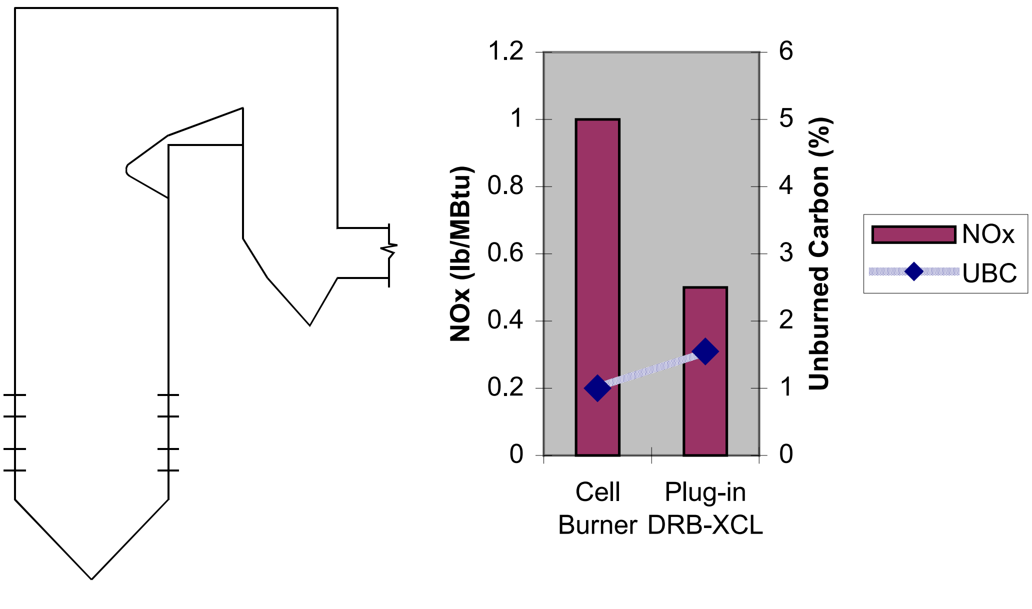


Figure 8: Pre and Post NOx With Staged DRB-XCL Burners and Higher Fineness

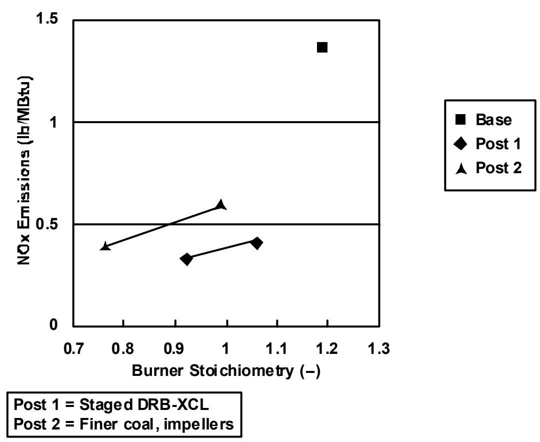
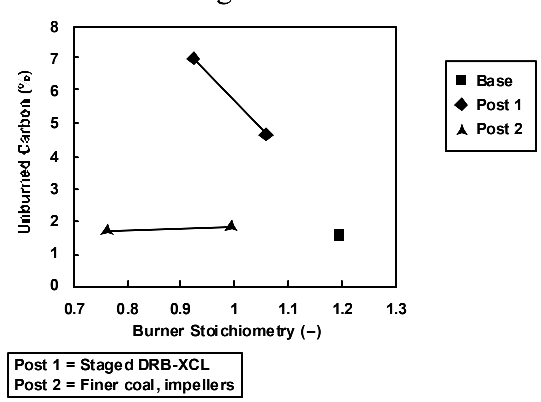


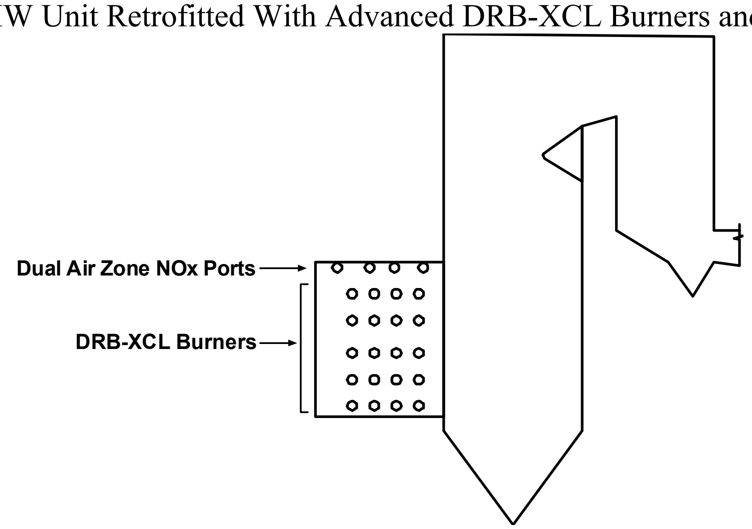
Figure 9: Pre and Post UBC with Staged DRB-XCL Burners and Higher Fineness



Several years later, the pulverizers were removed and replaced with B&W 89 mills with DSVS™ rotating classifiers. In addition, bladed impellers were installed in the burners. Operating the new system at low burner zone stoichiometry resulted in NOx emissions of less than 0.40 lb/MBtu with UBC near 2%. For example, NOx of 0.36 lb/MBtu was accompanied by UBC of 1.8%. Coal fineness was improved to ~70% minus 200 mesh, but with over 97% minus 100 mesh and 99.99% minus 50 mesh. Excellent combined NOx and UBC was achieved with staged DRB-XCL burners and increased coal fineness.

A third example combines the advantages of the plug-in DRB-XCL burner with higher coal fineness. This was performed on a pair of "identical" 583 MW units, each with five B&W 89 mills serving five elevations of burners (see Figure 10). Each unit was equipped with 40 DRBs as original equipment. The units fire some variety of import coals, but baseline and post retrofit tests were performed with bituminous coal with FC/VM of 1.4 – 1.55, 10-15% ash, and ~11,000 Btu/lb. This equipment was baseline tested and indicated NOx of 0.34 lb/MBtu with UBC of 8 – 10% on one unit. UBC was 4 to 5% on the other unit but NOx was not tested (see Figure 11).

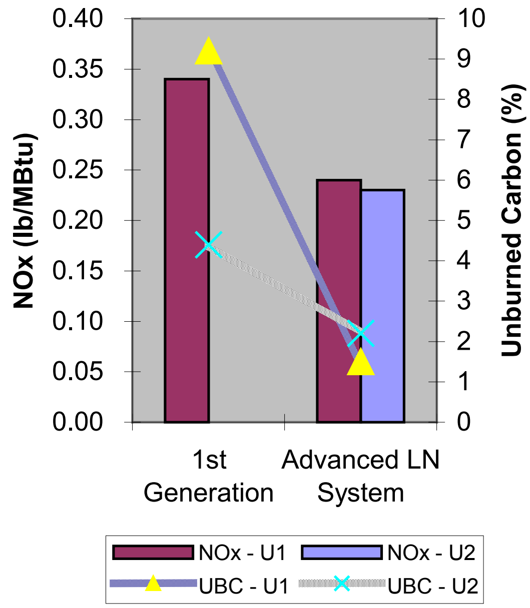
Figure 10: 583 MW Unit Retrofitted With Advanced DRB-XCL Burners and Higher Fineness



The customer needed to further reduce emissions on these units due to changes in NOx regulations. Consequently B&W received a contract to upgrade the units in several respects. DSVS classifiers and Variable Loading Systems were installed on all ten B&W 89 pulverizers. The DRBs were removed and replaced with plug-in DRB-XCL burners. Air staging systems were numerically modeled to optimize port quantity and placement. Dual Air Zone NOx ports were accordingly supplied with associated compartmented windboxes, air measurement equipment, ductwork, dampers and controls. Post retrofit results showed full load NOx was reduced to 0.23 - 0.24 lb/MBtu, which is exceptionally low for a bituminous coal fired unit. Simultaneously the unburned carbon was reduced to 2.2% on one unit, and 1.5% on the other—again excellent results with bituminous coal. CO emissions were less than 100 ppm with the new system.

These results indicate the potential for state-of-the-art low NOx systems for combined reductions in NOx and unburned combustibles firing bituminous coal.

Figure 11: NOx and UBC With Original DRB Compared to Advanced System

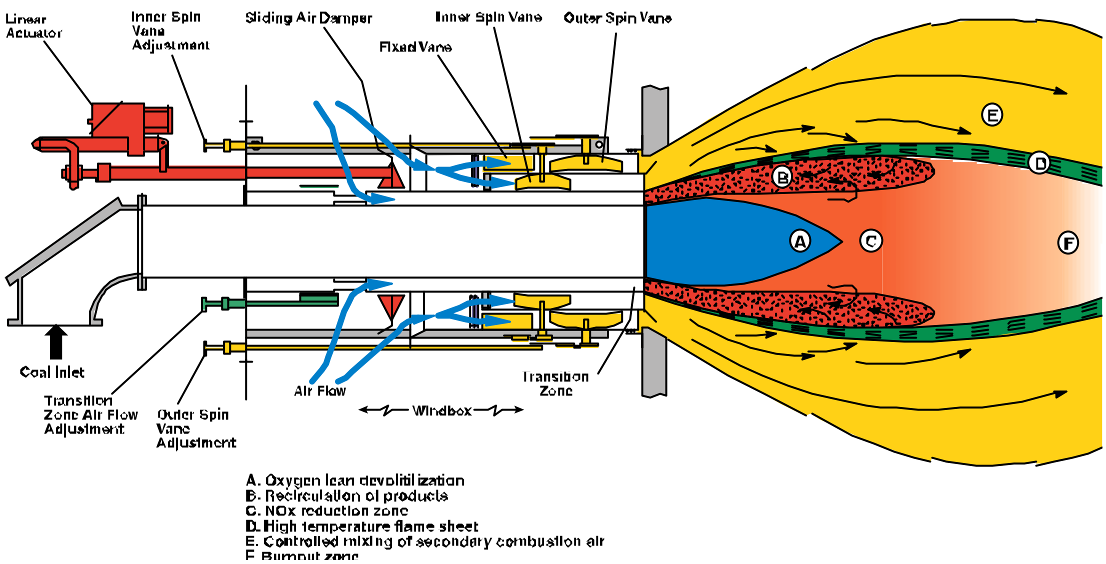


ULTRA LOW NOx COMBUSTION SYSTEMS

B&W embarked on a program in the mid-90s, with support of the U.S. Department of Energy, to develop an ultra low NOx burner. The burner was conceptually developed using proprietary computational fluid dynamic computer modeling, which uncovered the potential advantage of an additional air zone surrounding the burner nozzle. This air zone could better control critical aspects of mixing around the core of the flame as devolatilization and initial char reactions take place. The so-called transition zone acts as a buffer between the fuel-rich flame core and the secondary air supplied through two successive air zones outboard of the transition zone. NOx formed in the oxygen-rich outer flame region can be reduced back to other nitrogenous species in the flame core. The transition zone can impact the stoichiometry and air/fuel mixing rate in the core of the flame.

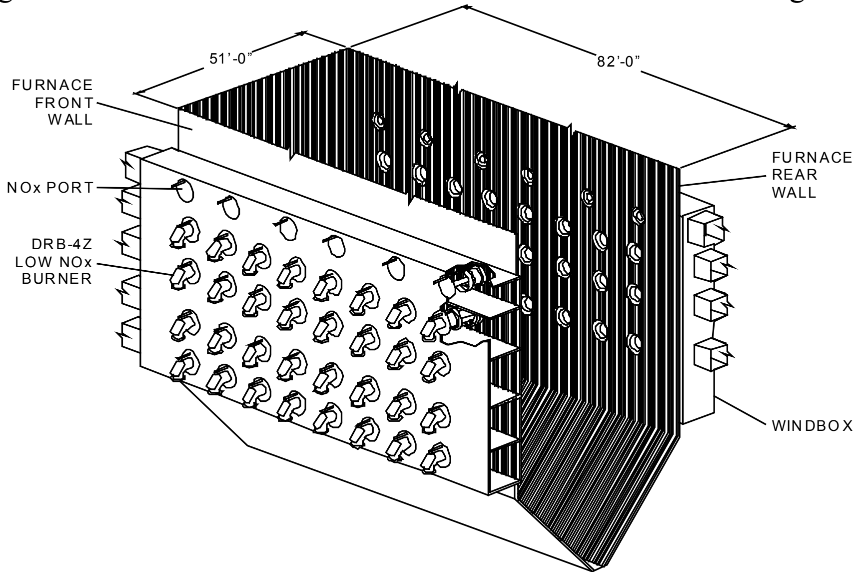
A prototype burner was designed, constructed, and refined through an extensive program of large scale combustion tests in the CEDF. Ultimately the new burner, named the DRB-4Z™, reduced NOx 25 to 40+% beyond B&W's most advanced dual air zone burner (Figure 12). These reductions were accomplished on subbituminous (PRB) and several bituminous coals.
The construction of the DRB-4Z draws heavily on the DRB-XCL burner, thus providing mechanical reliability. The coal nozzle, barrel arrangement, sliding air damper, pitot grid, and adjustable vanes follow design practice of the XCL as previously described. Heavy stainless steel construction assures durability like the XCL. The DRB-4Z is shop assembled in one unit to facilitate installation.

Figure 12: Low NOx DRB-4Z Burner Combustion Zones



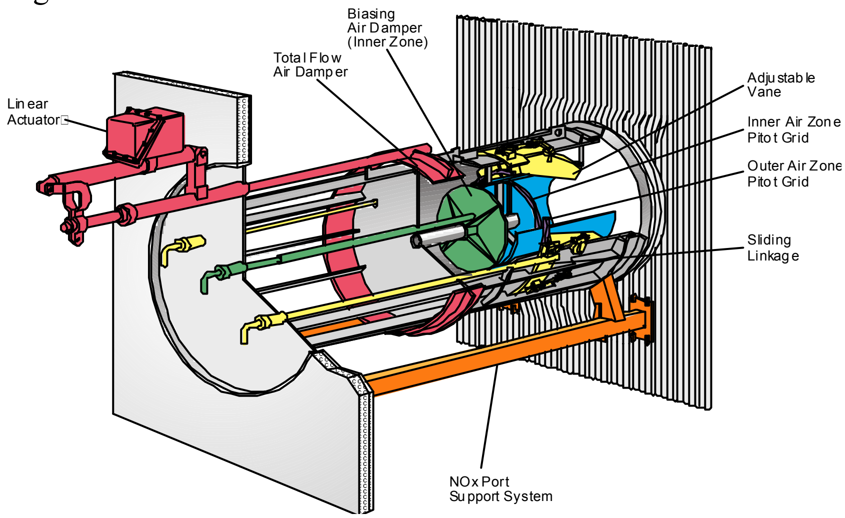
Several units are now in service with DRB-4Z ultra low NOx combustion systems, with additional units in various stages of design/fabrication/commissioning. The first went into service in 2000 at Reliant Energy's W. A. Parish plant, Unit 6, and Unit 5 followed in 2001. These are nominal 690 MW units which primarily fire PRB coal, but can also fire natural gas. The units were originally equipped with 56 DRBs arranged in compartmented windboxes as shown in Figure 13. These were replaced with DRB-4Z burners which plugged into the existing wall openings. New FPS gas lighters were supplied with the burners. Computer modeling was conducted to determine the optimum arrangement of NOx ports. Twelve Dual Air Zone NOx ports (Figure 14) were provided per the arrangement shown in Figure 13. The Dual Air Zone NOx port provides on-line adjustment of jet penetration and close-in air mixing with the furnace

Figure 13: W.A. Parish 6 – Retrofit Burner and OFA Port Arrangement



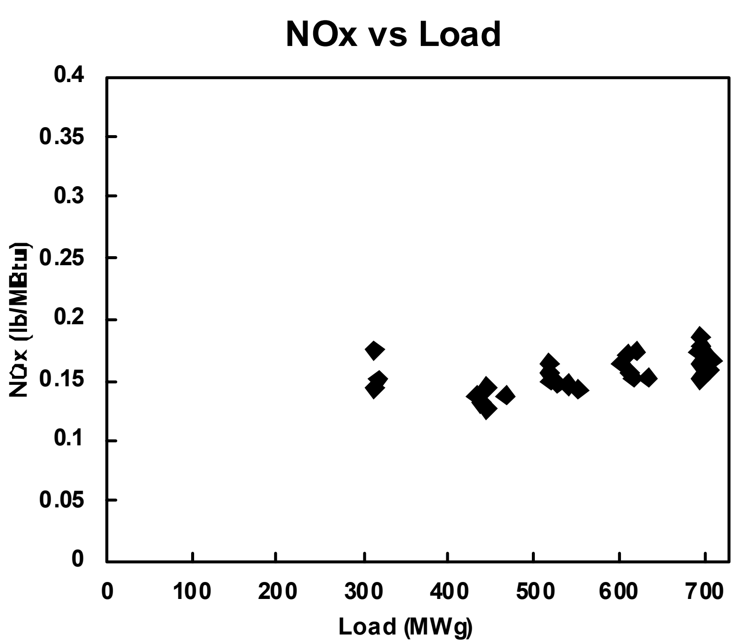
gases to facilitate emission control. The NOx ports were arranged in compartmented windboxes with air foils and dampers to measure and regulate air flow to the NOx ports.

Figure 14: Dual Air Zone NOx Port With Total Air Flow Control



Pre-retrofit tests showed the original DRBs were performing well with NOx emissions of 0.35 lb/MBtu at full load on Unit 6. The new low NOx system was installed / commissioned in Spring/Summer 2000. Full load NOx emissions were reduced to 0.17 lb/MBtu or below, representing 51% reduction from the original system (Figure 15). CO emissions were about 100 ppm at full load and negligible at reduced loads. UBC was typically 0.3%, essentially unchanged from prior results.

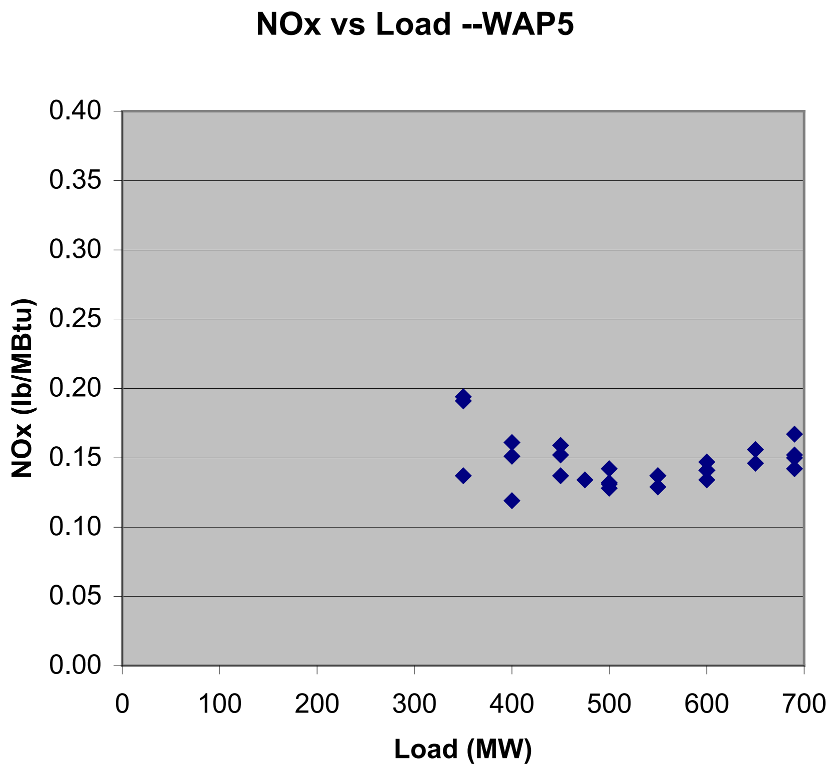
Figure 15: NOx Emissions for W.A. Parish 6 – DRB-4Z Burner Retrofit



NOx emissions were even lower on Unit 5, with baseline NOx about 0.30 lb/MBtu. Full load emissions were reduced to 0.15 lb/MBtu, for 50% reduction (see Figure 16). As with unit 6, NOx reduces with load over the upper half of the load range. NOx below half load depends on the number of mills in service and other operating conditions. Full load CO emissions were typically 50 to 100 ppm, and negligible at part loads. UBC was typically near 0.3% again.

In summary, the DRB-4Z has demonstrated NOx emissions on the order of 0.15 lb/MBtu in combination with a well designed air staging system when firing PRB coal, and simultaneously provided low CO and very low unb/urned carbon. This represents 50% NOx reduction over the first generation DRB. Large PC-fired units firing PRB, in absence of any NOx controls, typically produce NOx on the order of 1.0 lb/MBtu. So the ultra low NOx DRB-4Z system achieved NOx reductions of over 80% relative to typical uncontrolled levels.

Figure 16: NOx Emissions for W.A. Parish 5 – DRB-4Z Burner Retrofit



CONCLUSION/SUMMARY

Coal continues to be the dominant fossil fuel for electrical power generation in the U.S., and its usage could grow in response to energy demands. B&W's dedication to advancing low NOx combustion is attested to by over 100,000 MW of generating capacity, which cover the gamut of combustion systems – single wall, opposed wall, and roof fired; tangentially fired; and cyclones. Some of the first and second generation low NOx burners proved fairly effective in NOx control, but often at the expense of higher unburned carbon. Advanced low NOx systems have proven even more effective at reducing NOx, and can simultaneously minimize unburned carbon. These systems can provide significant reductions when retrofitted in place of first generation systems, and may offer an alternative to SCR systems.

KEY WORDS

Babcock & Wilcox
Burners
Combustion systems
Dual Register Burner
NOx control
OFA
Pulverized coal
Reliant Energy
SCR
UBC