Ultra-Low NO_X Integrated System for Coal Fired Power Plants

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Abstract

ALSTOM Power, Inc. (ALSTOM) is developing an Ultra-Low NO_X Integrated System for Coal Fired Power Plants to address present and anticipated NO_X emissions control legislation for US coal-fired boilers. The proposed system will build on ALSTOM's field-proven TFS 2000™ low NO_X firing system to achieve furnace outlet NO_X emissions at or below 0.15 lb/MMBtu for existing tangentially fired boilers firing a wide range of coals. Target NO_X emissions will be obtained without increasing the level of unburned carbon in the fly ash through advances in firing technology including in-furnace, combustion process modifications, and a post-combustion carbon burnout technology for non-reactive coals. In addition, an advanced control system incorporating neural-net features may be employed to maintain target NO_X emissions over the range of boiler operation and load. The advanced control system may employ new sensor technology including coal flow measurement in each feed line to control NOx formation during combustion and other system optimization variables. The cost of the proposed system is anticipated to be less than half that of the present, state-of-the-art, selective catalytic reduction (SCR) process. This integrated system should be available for market application in 2002.

This effort, led by ALSTOM, is supported by team members including Consumers Energy; Indianapolis Power & Light; Massachusetts Institute of Technology; Progress Materials, Inc.; Scottish Power; Reliant Energy; U.S. DOE/NETL and Dominion Generation.

This project includes pilot scale testing at ALSTOM's US Power Plant Laboratory Drop Tube Furnace System (DTFS), Pulverizer Development Facility (PDF), and 17.5 MW_t Boiler Simulation Facility (BSF). This 21-month project is expected to culminate in utility-scale products, which ALSTOM should make commercially available in 2002. This paper provides a status report of the project development efforts.

1.0 Introduction

The US power generation industry is undergoing complex change from demands for deregulation and environmental responsibility. Deregulation is driving economic efficiency with ever increasing sensitivity to minimizing capital investment, reducing operational costs, and controlling uncertainty and resultant financial risk. In this environment, existing coal-fired power plants with paid down capital investments may enjoy a favorable role in base load generation due to low fuel costs, high availability and capacity factor, and generally low cost of electricity production. The needs for the electric-utility industry are to improve environmental performance, while simultaneously improving overall plant economics. This means that emissions control technology is needed with low capital and operating costs.

The 1990 CAAA Title I, Urban Air Quality, and anticipated future National Ambient Air Quality Standards (NAAQS) go further in forcing NOx emissions reductions than previous Title IV ("Acid Rain")

Phase I and Phase II. Under Title I, the US EPA has issued a State Implementation Plan (SIP) call for 22 eastern states and the District of Colombia to reduce both NOx and VOC's from existing plants on the basis of ozone non-attainment in the northeast. EPA's analysis includes 37 states east of the Rockies with assumption of full compliance of the existing Title IV regulations first. EPA has given the 22 eastern states a NOx budget based on the less stringent of 85% reduction from 1990 levels or 0.15 lb/MMBtu for utility units and a 70% reduction for non-utility sources. The SIP's will need to directly address compliance in the five-month (May through September) ozone season. In addition to meeting the current emissions regulations, boiler owners must also anticipate future regulations.

The impact of impending regulations is difficult to determine. In many ways utility boiler owners are the best source of knowledge about possible environment control strategies for their various regulatory and cost environments. A survey conducted by ALSTOM of over 20 customers located in the 22 State Ozone Transport Region and in Texas, including Investor Owned Utilities, Public Owned Utilities, and Industrial customers showed:

- Customers anticipate that NOx trading will be integral to their compliance strategy,
- Most customers saw themselves as net buyers of NOx credits with prices expected in the $2,000 to $3,500 / ton NOx range,
- Utilities want alternatives to SCR, especially for units that are not base loaded,
- Utilities are comfortable with fuel switching strategies as part of a compliance strategy,
- Utilities and industrials see limited use of SNCR and gas reburn, and
- All customers would be pleased to have additional options for achieving lower cost NOx compliance at the 0.15 lb/MMBtu level

These environmental factors and utility owner interests are the motivations for an ongoing development program by ALSTOM, supported by the US DOE, which is discussed herein.

2.0 Background

ALSTOM has undertaken an approach to solving environmental compliance needs through the creation of a total environmental solutions team that utilizes the full range of specific product resources and talents throughout the company. The team begins a compliance strategy by considering all of the potential places within the steam generating system where NOx can be controlled. An evaluation is made of the fuel selection, preparation, pulverization, and combustion. All feasible options for in-furnace NOx control are reviewed for reduction efficiency and potential impact on steam generator performance. Post-combustion technologies are also a major component of the evaluation. ALSTOM has expertise in post combustion systems including SCR, SNCR and hybrid technologies. A total approach to integrated controls and measurement is an integral part of this evaluation. This approach provides the flexibility to invest capital on equipment that provides the most cost-effective NOx reduction strategy, thus minimizing the total capital and operating costs for system-wide compliance.

ALSTOM has supported customer requirements to address CAAA of 1990 rules by offering a broad line of low NOx firing system products. Customer requirements have been met in many cases with in-furnace solutions alone. With the wide variety of tangential fired boiler designs of varying vintage, along with a broad range of coals being fired, ALSTOM developed and provides a retrofittable family of low NOx firing system products which includes Level I, II, and III LNCFS™, LNCFS™-P2, and TFS2000™R technology. Figure 1 shows the relative costs and reduction efficiencies of ALSTOM's Low NOx solutions, all based on a typical single furnace 200 MW boiler.

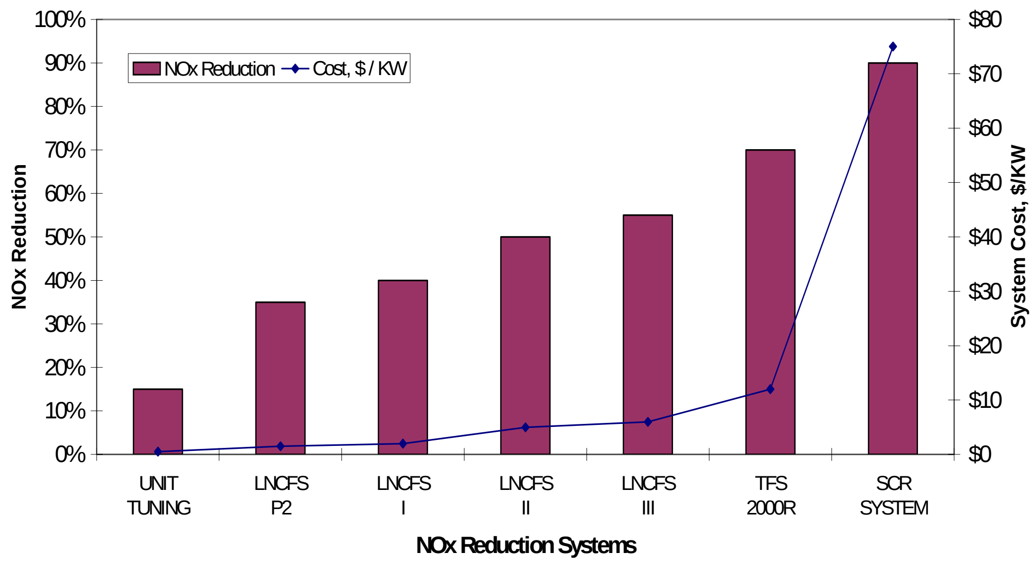

Figure 1. NOx reduction system cost vs performance.

Each of these low NOx firing system products utilizes the same basic design features of air-staged combustion, early fuel devolatilization, and local combustion air staging. In general, in applying these systems, unburned carbon increases inversely with NOx reductions; more highly loaded (hotter) furnaces generate higher NOx and additional waterwall deposits; smaller furnace volumes result in higher carbon losses or less ability to reduce NOx; lower rank coals result in lower NOx emissions as well as lower unburned carbon levels; and boiler efficiency may be negatively impacted slightly, primarily due to increased unburned carbon levels. The differences among the options available occur in the tradeoffs between the extent of NOx emissions reduction and the complexity and cost of material modification and retrofit requirements. The percent decrease in NOx emissions from baseline is unit and fuel specific.

ALSTOM has been supplying overfire air-based NOx reduction systems since 1970 and has been supplying its family of NOx control firing systems since 1980. Over 175 coal-fired tangential boilers have incorporated these systems, representing over 57,000 MWe of generating capacity. These unit retrofits range in size from 44 MWe industrial to a 900 MWe supercritical, divided unit. The retrofit experience covers an extensive range of coal types from lignites to bituminous [1].

TFS 2000™R represents the most aggressive NOx reduction firing system technology available that includes features to mitigate increases in unburned carbon in fly ash from units firing high rank coals and increases in carbon monoxide emissions from units firing low rank coals. NOx emission levels below

0.15 lb/MMBtu have been achieved and maintained by TFS2000™R on a continuous basis in some units firing lower ranked coals. Prior to the demonstrated success of ALSTOM's technology to achieve that low level of NOx emissions, it was universally thought that installation of an SCR would be required. The magnitude of potential cost savings available by avoiding an SCR installation while maintaining NOx emissions below 0.15 lb/MMBtu demands development of such a NOx reduction firing system for a larger proportion of the installed tangential fired boiler population. The success to date with lower rank coals and TFS2000™R suggests that these objectives should be achievable.

3.0 TFS 2000™R System Design

The design philosophy of the TFS 2000™R firing system (Figure 2) is based on the integration of precise furnace stoichiometry control, pulverized coal fineness control, initial combustion process control, and concentric firing via CFS™ [1]. This represents the most advanced in-furnace combustion NOx control system. Multiple levels of separated over-fire air (SOFA) are used to maximize NOx reductions while limiting CO emissions or increases in unburned carbon. Depending on the type of coal, DYNAMIC™ Classifiers may be added to the pulverizers to control coal fineness and further limit unburned carbon.

Current, field retrofit TFS 2000™ systems have demonstrated NOx emissions below 0.25 lb/MMBtu when firing an Eastern bituminous [3] and below 0.15 lb/MMBtu when firing a Western sub-bituminous coal (PRB) [4]. Table 1, a summary of the TFS2000R NOx retrofit experience to date, shows that seven retrofit units are currently in operation and 11 more are currently under contract.

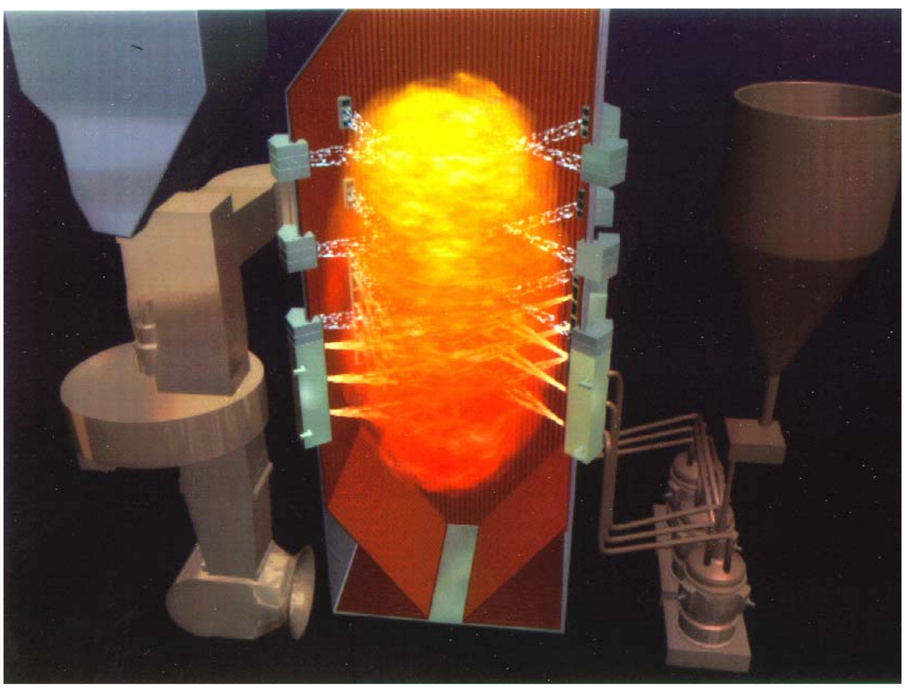

Figure 2. TFS 2000™R Low NOx Firing System

Table 1. TFS 2000™R NOx retrofit experience.

Unit ID	MWe	Project Status	NOx Emissions lb/MMBtu	Fuel Type
A	650	In Service	< 0.25	East. Bit.
B	550	Contract		PRB
C	265	Contract		PRB
D	150	Contract		PRB/Bit. Blend
E	325	In Service	< 0.13	PRB/Bit. Blend
F	500	Contract		MW Bit.
G	600	In Service	< 0.15	PRB
H	600	Contract		PRB
I	560	Contract		MW Bit.
J	200	Contract		PRB
K	325	Contract		PRB
L	580	In Service	< 0.15	PRB
M	580	Contract		PRB
N	325	In Service	< 0.15	PRB
O	275	Contract		PRB
P	532	In Service	< 0.15	PRB
Q	400	In Service	< 0.25	East. Bit.
R	274	Contract		PRB

4.0 Ultra Low NOx Integrated System

An Ultra-Low NOx Integrated System is under development with the goal of controlling NOx emissions to < 0.15 lb/MMBtu with Eastern bitumious coal and < 0.10 lb/MMBtu with subbituminous coal. The proposed Ultra Low NOx Integrated System will be an aggressively air staged, in-furnace NOx reduction system designed to meet or exceed the DOE NOx target of 0.15 lb/MMBtu for tangentially fired boilers, firing a wide range of coals. This system will build upon the performance of ALSTOM's commercially available low NOx firing system technology, making it suitable for commercial deployment by 2002. Using the known cost of existing, in-kind technologies, the commercial cost of the proposed system is anticipated to be less than half (<50%) that of an SCR-only system, exceeding the desired 25% levelized cost savings.

The foundation for the integrated system is ALSTOM's field-proven TFS 2000^{TM} low NOx firing system (Figure 2). The Ultra Low NOx Integrated System will improve NOx reduction over the current TFS 2000^{TM} system through advances in several areas, including new technologies to alter the troublesome trade-off between NOx and unburned carbon levels. These improvements in both components and processes, described below, are based on fundamentally sound principles which are known to lower NOx formation and/or to improve NOx destruction, while minimizing the impact on the balance of plant.

New developments include milling system enhancements to the mill internals and the coal particle size classification processes. ALSTOM Power's Dynamic™ Classifier (Figure 3) will be used to produce a finer coal product with more rigorous control over particle top size. Additionally, pulverized coal transport air quantities may be decreased to give a lower transport air to coal mass ratio. The transport air-to-fuel ratio may be decreased by separating the fuel and air after exiting the mill, thus generating a fuel rich coal stream and a fuel lean transport air stream. These improvements will allow more rapid heating of the coal particles in the burner near field, resulting in greater fuel bound nitrogen release, and hence lower NOx, as well as lower unburned carbon at the exit of the upper furnace.

Figure 3. ALSTOM Power's Dynamic™ classifier.

Low NOx oxidizing pyrolysis burners, based on ALSTOM's LNCFS™-P2 coal nozzle tips (Figure 4), may include design improvements to promote higher fuel nitrogen release through more rapid heating of coal particles. Operated with the fuel rich fraction of the transport air and coal mixture, these burners will minimize the formation of near field NOx via control over the local stoichiometry and mixing processes. Modifications will include the generation of additional near burner turbulence to create a more uniform, high intensity, fuel-rich zone. Effective mixing of combustion products in the fuel-rich lower furnace, coupled with longer residence times, will result in greater NOx destruction.

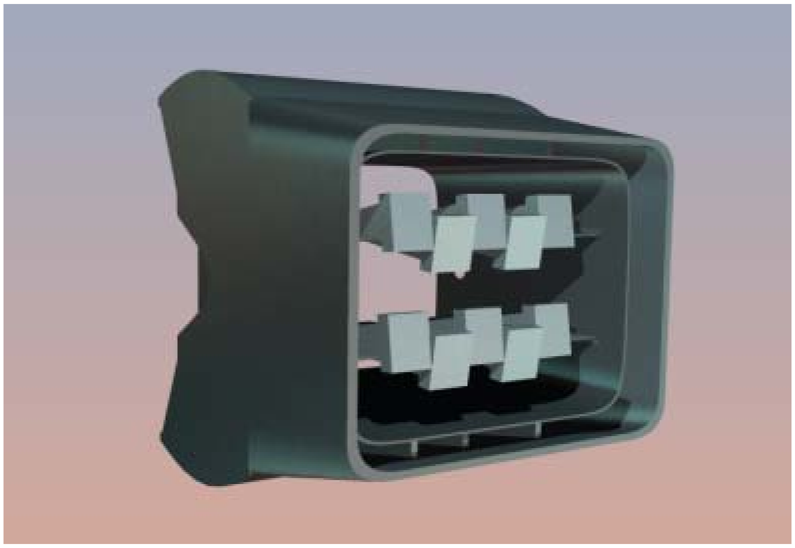

Figure 4. ALSTOM Power's LNCFS™-P2 coal nozzle tip

If the separation system to reduce the transport air to fuel ratio is incorporated into the overall ultra low NOx system design, the fuel lean transport air, carrying the finer fraction of the pulverized coal stream, could be directed to a close coupled or intermediate elevation overfire air register in order to provide further NOx reduction through the reburn mechanism. Optionally, selective non-catalytic reduction (SNCR) may be employed in the reburn zone, or further downstream, if further trimming of NOx is required.

Overfire air velocities and trajectories will be modeled and tested as a means to optimize SOFA mixing higher in the furnace to permit longer residence time in the lower furnace, fuel rich zone while not unduly sacrificing carbon burnout. The impact of SOFA configuration on the oxygen distribution predicted by computational fluid dynamics (CFD) modeling is illustrated in Figure 5. Similarly, ALSTOM's patented Concentric Firing System (CFS™) will be used to provide additional near field air staging and promote the formation of an oxidizing environment near the waterwall to mitigate against waterwall wastage. Underfire air may also be implemented as an additional means to provide air staging, while simultaneously promoting oxidation of bottom ash carbon and improving the heat absorption in the lower furnace.

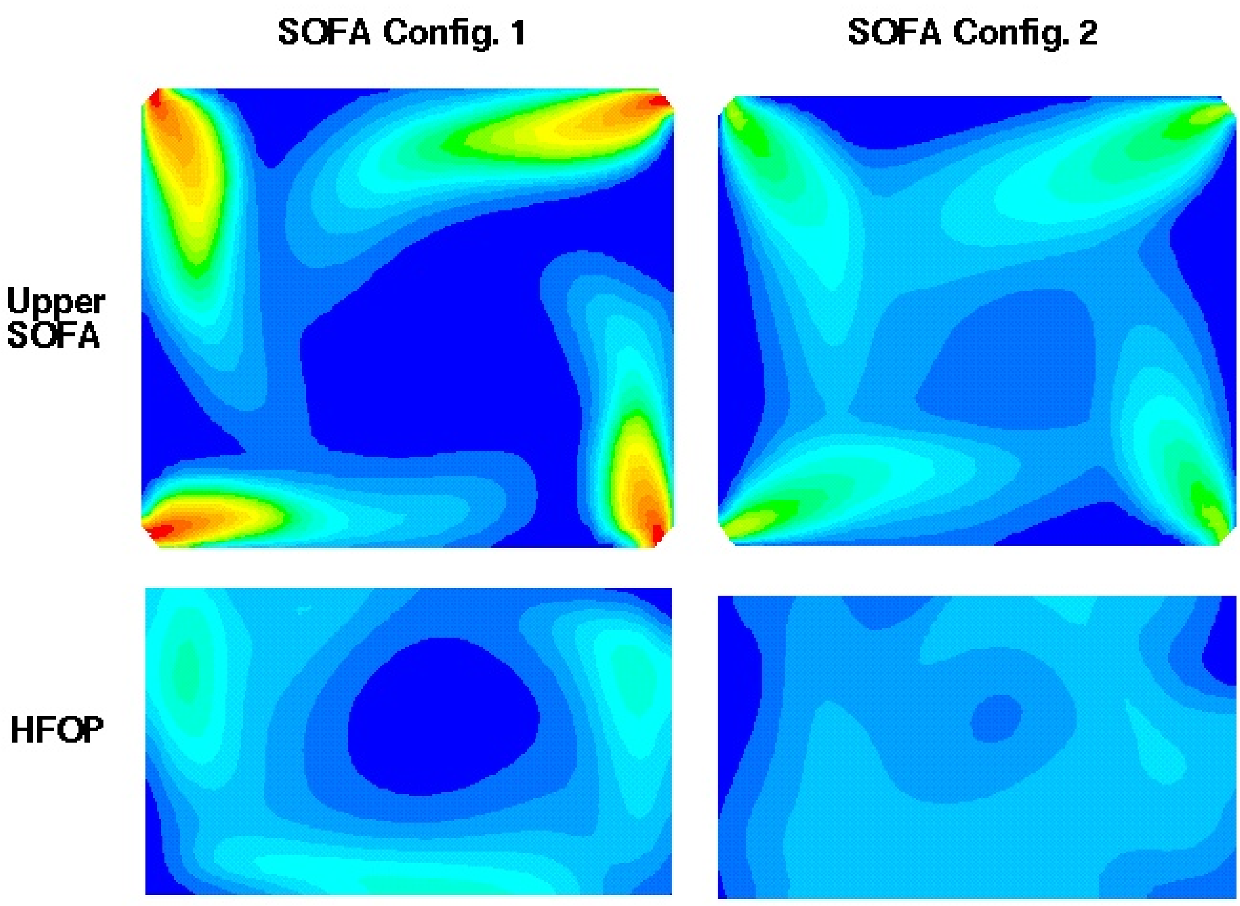

Figure 5. CFD predictions of oxygen mole fraction as a function of SOFA configuration at upper SOFA elevation and HFOP (horizontal furnace outlet plane – boiler arch).

For particularly unreactive coals where high levels of unburned carbon in the fly ash might prevent selling the ash, a bubbling bed Carbon Burn Out™ combustor (Figure 6) developed by Progress Materials, Inc. may be used to oxidize the carbon to acceptable levels. Having the ability to reduce the carbon content of fly ash to commercially acceptable levels creates an additional degree of freedom for NOx control. Economics of the bubbling bed system are addressed solely through its operation as a heat recovery and saleable fly ash product device.

Figure 6. Field installation of the bubbling bed Carbon Burn Out™ combustor (Progress Materials, Inc.).

An advanced neural net control system may be employed to maintain target NOx emissions by controlling both local and global stoichiometries over the range of boiler operating loads and to provide for fault tolerant operation as planned and unplanned system upsets occur. The advanced control system will diagnose the combustion process through existing instrumentation and employ advanced sensor technology including: a carbon-in-ash analyzer, coal mass flow measurements in each fuel transport line, and advanced flame scanning spectrophotometers at each fuel nozzle. Collectively, the advanced control components will provide optimum system performance across a range of input parameter variations, providing minimum NOx emissions while simultaneously maintaining desired steam temperatures, carbon in ash levels, and optimizing plant heat rate.

5.0 Large Pilot-Scale Combustion Testing

The Ultra-Low NO_X Integrated System for Coal Fired Power Plants is being developed under a cooperative agreement with the U.S. DOE. Included in the project is characterization of the test fuels in ALSTOM's Drop Tube Furnace (DTFS), large pilot-scale demonstration of the system components in ALSTOM's Boiler Simulation Facility (BSF) shown in Figure 7, and an engineering and economic analysis of the overall system.

Figure 7. ALSTOM Boiler Simulation Facility located in Windsor, Connecticut

The project scope includes BSF testing of three coals, a medium volatile bituminous (mvb), a high volatile bituminous (hvb), and a sub-bituminous coal. These coals span the range of coals typically fired in pulverized coal-fired utility boilers in the U.S. The medium volatile coal was fired first (Nov. 2000) as it provided the greatest challenge for NOx reduction due to the low volatile matter / reactivity of the coal. High levels of carbon in the fly ash (CIA) were also expected for the low-reactivity fuel that would allow the impact of the various components in the Ultra Low-NOx system on the CIA levels to be more easily quantified. BSF testing of the sub-bituminous and high volatile bituminous coals is currently planned for the end of March, 2001.

The ASTM analysis of the mvb coal fired in the BSF is shown in Table 2. The coal was first fired in a drop-tube furnace (DTFS) to better understand the reactivity of the coal. Figure 8 compares the carbon in ash as measured in the DTFS for the mvb test coal (30%) to other high volatile bituminous coals that have been fired in the same facility under the same test conditions. The DTFS results are consistent with expectations that the chosen test fuel is a difficult fuel to burn to completion and will present a challenge with regard to maintaining unburned carbon emissions under staged conditions during the pilot-scale test campaign.

Table 2. ASTM analysis of medium volatile bituminous coal fired in BSF.

Proximate		Ultimate	
VM	22.5%	Hydrogen	4.0%
FC	63.1%	Carbon	74.7%
Moisture	0.9%	Sulfur	1.4%
Ash	13.6%	Nitrogen	1.3%
		Oxygen	4.2%
FC/VM	2.8		
HHV, BTU/lb	13,109		

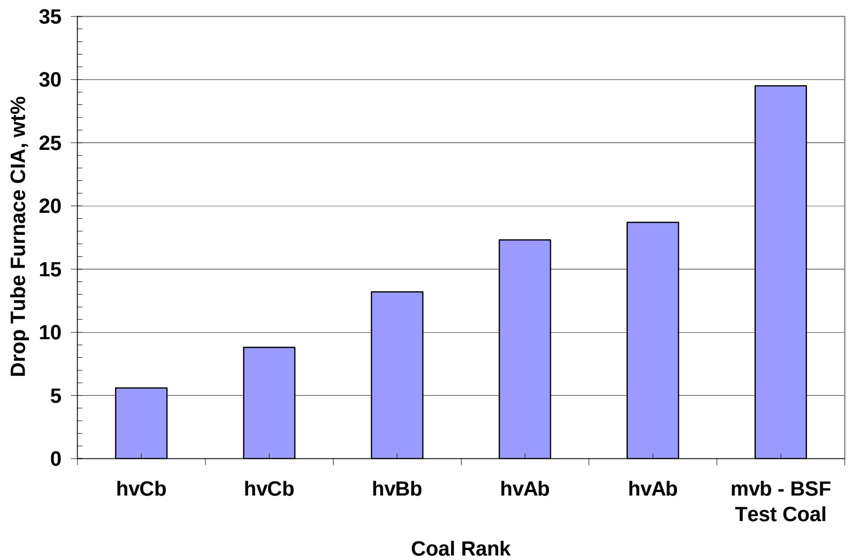

Figure 8. Drop-tube furnace carbon in ash for a range of bituminous coals.

Approximately 50 combustion tests were performed in the BSF at 57 MMBtu/h to characterize the combustion characteristics of the low reactivity fuel and to evaluate the proposed concepts to achieve lower NOx emissions. Figure 9 shows the measured NOx and CIA as a function of the main burner zone (MBZ) stoichiometry. As expected, the NOx decreases as the MBZ stoichiometry decreases, but at the expense of additional unburned carbon in the fly ash. The measured NOx values for the mvb coal ranged from a high of 0.80 to a low of 0.23 lb/MMBtu, while the CIA increased from approximately 2 – 12 %. Similar curves as a function of MBZ stoichiometry for a high volatile B bituminous coal (from a previous BSF test campaign) are also shown in Figure 9. The more reactive fuel shows similar trends of decreasing NOx and increasing CIA as the MBZ stoichiometry decreases. However, the more reactive fuel is able to achieve significantly lower NOx emissions due to the increased release of fuel-bound nitrogen in sub-stoichiometric regions of the BSF.

Among the interesting results obtained from the recent BSF combustion testing was the effect of coal grind on both the NOx and unburned carbon in the fly ash. Two coal grinds were evaluated: a fine grind (available with a Dynamic™ Classifier) and a micro-fine coal grind. NOx emissions for the micro-fine grind coal were lower than those of the fine grind coal for a range of main burner zone stoichiometries when firing the medium volatile bituminous test coal. Average NOx emissions reductions were approximately 15% when firing the micro-fine coal under the same conditions as the fine grind coal. Utilizing the micro-fine coal results in a reduction in carbon in the fly ash of approximately 45% across a range of main burner stoichiometries. These results emphasize the benefit of reductions in coal particle size as a means to improve both combustion efficiency and NOx emissions for low reactivity coals under staged combustion conditions.

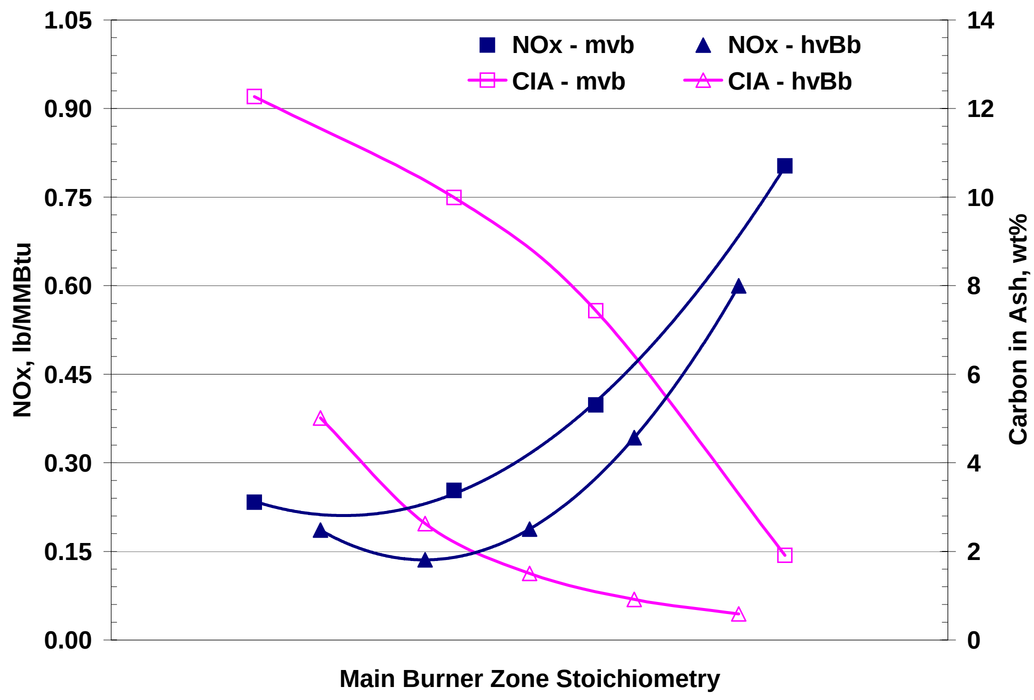

Figure 9. BSF measurements of NOx and CIA vs MBZ stoichiometry and coal rank.

6.0 Engineering and Economic Analysis

In addition to the experimental work, preliminary engineering and economic analysis studies were performed in order to assess the cost – benefit of each of the Ultra Low NOx Integrated System components. For this work, seven Ultra Low NOx Integrated System combinations were evaluated as applied to a hypothetical 500 MWe pulverized coal fired utility boiler firing a typical, high volatile bituminous coal. Evaluated systems included:

Case 1 - Base Case (pre-retrofit)
Case 2 - Base Case with SCR
Case 3 - Base Case with TFS 2000™
Case 4 - Base Case with TFS 2000™ & SCR
Case 5 - Base Case with TFS 2000™ & Advanced Controls (transport air & coal flow balancing, advanced neural net technology, and local stoichiometry control)
Case 6 - Base Case with TFS 2000™, Advanced Controls & Firing System Optimization Components (P2 Coal Nozzle Tips, Transport Air & Fuel Separation / Coal Fines Injection, & High Velocity Overfire Air)
Case 7 - Base Case with TFS 2000™, Adv. Controls, Firing System Optimization & SNCR
Case 8 - Base Case with TFS 2000™, Adv. Controls, Firing System Optimization & SCR.

For this work, analysis inputs included expected system NOx emissions (lb/MMBtu), carbon heat loss (% of MCR heat input), fan power consumption (kW), booster fan power consumption (kW) (as required), mill power consumption (kW), NH3 reagent costs, SCR power / draft loss (kW), and plant heat rate (Btu/kWh). Economic assumptions included 25 year life, 3% inflation rate, 50% equity/debt ratio, and a 7% discount rate.

Results of the preliminary engineering and economic analysis studies are that four Ultra Low NOx System combinations are forecast to provide NOx emissions at or below 0.15 lb/MMBtu when firing a high volatile bituminous coal. These four are: Case 2, the base case with SCR; Case 4, the base case with TFS 2000™ and SCR; Case 7, the base case with TFS 2000™, advanced controls, firing system optimization & SNCR; and Case 8, the base case with TFS 2000™, advanced controls, firing system optimization & SCR. Of these, Case 6, which avoids the addition of an SCR, is the most cost effective, being forecast to be 44% less costly on a $/ton of NOx removed basis than an SCR only solution (Case 2).

Following this line of reasoning, solutions focusing on combustion process modification, such as TFS 2000™, TFS 2000™ plus advanced controls, and TFS 2000™ plus advanced controls plus additional firing system optimization improvements, were up to 73% less expensive per unit NOx reduction than the SCR only solution. However, the ability of these solutions to meet the desired program target of 0.15 lb/MMBtu across the range of boiler sizes and fuel types is still to be proven within the ongoing subject project.

7.0 Summary

Progress has been made to develop an ultra-low NOx Integrated System for tangentially fired coal boilers towards the goal of achieving furnace NOx emissions at or below 0.15 lb/MMBtu firing a wide range of coals. The cost effectiveness of in-furnace approaches over SCR based solutions has been shown, and work continues in a collaborative program with US DOE support towards this goal.

8.0 References

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