NOx COMPLIANCE FOR EXISTING TANGENTIALLY-FIRED PULVERIZED COAL UNITS

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ABSTRACT

The US EPA Title I NOx emission limits, along with world-wide clean air regulations are mandating coal-fired NOx emission levels below 0.15 lb/MBtu. For tangentially fired units, experience has shown that the technology is currently available to achieve these limits. The question for each unit owner-operator becomes; what is the most economical technology or combination of technologies to achieve the required results?

This paper provides a brief overview of ALSTOM's latest in-furnace NOx control technologies for tangential coal-fired steam generators. The paper further reviews options of both stand-alone and combined multiple technologies to achieve the most cost-effective NOx compliance, while maintaining the high levels of unit efficiency and performance that is required to be successful in our deregulated power industry. Current operational data of in-furnace and NOx reduction systems are presented, as well as the latest historical cost data for the systems.

INTRODUCTION

Existing regulations and anticipation of even more stringent future emission guidelines have made selective catalytic reduction (SCR) post-combustion technology a virtual requirement for all new pulverized coal-fired applications. New unit designers have almost universally embraced the philosophy of combining both in-furnace and post-combustion NOx controls for pulverized coal-fired units. This multiple technology combination provides a comfortable operating margin for NOx emissions, while maintaining high levels of unit efficiency and reliability. Cost data has shown that the initial investment of an integrated NOx reduction system can pay off in increased catalyst life and reduced ammonia usage over a relatively short period.

The choice for owner/operators of existing units is not as clear cut. System designers are forced to work within the constraints of the existing furnace configuration, equipment interference, and various operating modes for in-furnace modifications. The cost of an in-furnace low NOx burner retrofit as well as the ultimate reduction efficiency of the firing system is highly unit and fuel specific. Likewise, unit backpass and air preheater arrangement as well as available real estate will have a major impact on the complexity and cost of post-combustion controls.

Unlike new unit philosophy, the use of an SCR is not a foregone conclusion for all existing units in order to meet local emission requirements. In countries where emissions "bubbling" is allowed, it is not absolutely necessary to achieve the maximum allowable emission limit on each unit. The main point to consider is that the most economical approach to meeting NOx emission limits is, where possible, to evaluate achieving the target on a system-wide basis rather than a single unit basis. Small capacity, higher emitting units may be offset by overcompliance on larger base-loaded units within the utility. Periodic emission excursions may be compensated through the trading of NOx credits. 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.

NOx COMPLIANCE STRATEGY

ALSTOM has undertaken an approach to solving environmental compliance concerns through the creation of a Total Environmental Solutions team that utilizes the full resources and talents of the following ALSTOM groups.

ALSTOM Air Preheater
ALSTOM Utility Boiler
ALSTOM Customer Services
ALSTOM Environmental Systems
ALSTOM Power Plant Laboratories
ALSTOM Project Trade Finance

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 virtually all post combustion systems including SCR, SNCR and hybrid technologies. A total approach to integrated controls and measurement is an integral part of this evaluation.

One of the most important factors to be considered is the construction aspect of installing these retrofit components and systems. ALSTOM has the capability to review installation plans and develop innovative solutions and cost estimates for these potentially difficult projects.

Equally important, an assessment is made of the impact each of these technologies has on every subsequent step of the steam generation process and the individual system components. All compliance technologies can impact equipment performance and reliability. It is critical to identify and quantify those impacts in the evaluation process so that they can either be minimized by design changes, or accepted and factored into the resulting financial evaluation.

Client input is essential for an accurate assessment of the retrofit technologies. Consideration must be made for plant load and dispatching requirements, as well as items such as long-term outage planning, future fuel changes, anticipated plant life, and evaluation of existing unit shortcomings such as air heater thermal performance, fan capabilities, plant controls, furnace and ductwork design pressures, etc.

The final step in the evaluation process is to determine the optimal economic solution. This could entail performing modifications to all affected units, or over-complying on selected units and doing limited or no control on others.

ALSTOM LOW NOx FIRING SYSTEMS

ALSTOM has developed a family of Low NOx firing systems to add5ress the specific needs of the wide variety of boiler designs of varying vintage, along with a broad range of coals being fired. The five basic systems, in ascending order of complexity, are the LNCFS™-P2 system, LNCFS™ Level I, II, and III systems, and the TFS 2000™R. The basic configuration of these systems is shown in Figure 1. All of the Low NOx firing system designs utilize the same basic design features of air-staged combustion, early fuel devolatilization and local combustion air staging. The differences among the options are 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 LNCFS™ based NOx control systems since 1980. Since 1980 218 coal-fired tangential boilers representing nearly 68,000 MWe of generating capacity have been retrofitted with an Alstom Low NOx firing system. These unit retrofits range in size from a 44 MWe industrial to a 900 MWe supercritical, divided unit.

NOx FORMATION MECHANISMS

The formation of NOx occurs through complex chemical reactions that are affected by unit design, operating conditions and fuel characteristics. Nitrogen oxides are known to form from the oxidation of both atmospheric nitrogen and nitrogen contained within fuel. These two distinct nitrogen sources produce NOx emissions known respectively as "thermal NOx" and "fuel NOx". The rate of thermal NOx formation, formed from decomposition of atmospheric molecular nitrogen, is highly dependent on the temperature and oxygen concentration within the firing zone. The percentage of fuel NOx formation, formed predominately from organically bound nitrogen in the coal, varies significantly with different coals and unit operating conditions. Fuel NOx can account for as much as 80 percent of the total NOx emissions on coal-fired units. Fuel NOx formation can be controlled by limiting the availability of oxygen during the combustion process. A third mechanism, originally proposed by Fenimore, describes the rapid formation of "prompt NOx" at the flame front, possibly through the reaction of hydrocarbon fragments with atmospheric nitrogen. It is generally accepted that the prompt NOx contribution represents less than five percent of the total NOx emissions and that low NOx firing system design and operation has limited influence on emissions generated via the Fenimore mechanism. Thus, to control overall NOx formation it is necessary to rapidly ignite the coal and control the temperature as well as the availability of oxygen during the coal combustion process.

OVERFIRE AIR

Overfire air is the most established and effective method for decreasing NOx emissions from pulverized coal tangentially-fired steam generators. The use of overfire air stages the combustion process by redistributing a portion of the secondary air above the main firing zone to decrease the amount of available oxygen within the main firing zone. Two types of overfire air configurations are utilized in ALSTOM's LNCFS™ technology: close-coupled overfire air (CCOFA), and separated overfire air (SOFA) arrangements. Separately or combined, they form the basis of the LNCFS™ system arrangements. See Figure 2 for a typical corner arrangement in an LNCFS™ Level III firing system and Figure 3 for a typical TFS2000™R firing system as designed for a low reactivity coal.

Standard Windbox	LNCFS P-2	LNCFS Level I	LNCFS Level II	LNCFS Level III	TFS2000R
					SOFA
					SOFA
			SOFA	SOFA	SOFA
			SOFA	SOFA	SOFA
AIR	VCCOFA	CCOFA	CCOFA	CCOFA	CCOFA
COAL	P2 COAL	CCOFA	COAL	CCOFA	COAL
AIR	CFS™ AIR	COAL	CFS™ AIR	COAL	CFS™ AIR
COAL	P2 COAL	COAL	COAL	COAL	COAL
AIR	CFS™ AIR	CFS™ AIR	CFS™ AIR	CFS™ AIR	CFS™ AIR
COAL	P2 COAL	COAL	COAL	COAL	COAL
AIR	CFS™ AIR	CFS™ AIR	CFS™ AIR	CFS™ AIR	CFS™ AIR
COAL	P2 COAL	COAL	COAL	COAL	COAL
AIR	CFS™ AIR	CFS™ AIR	CFS™ AIR	CFS™ AIR	CFS™ AIR
COAL	P2 COAL	COAL	COAL	COAL	COAL
AIR	AIR	AIR	AIR	AIR	AIR

FIGURE 1: ALSTOM LOW NOx FIRING SYSTEM OPTIONS

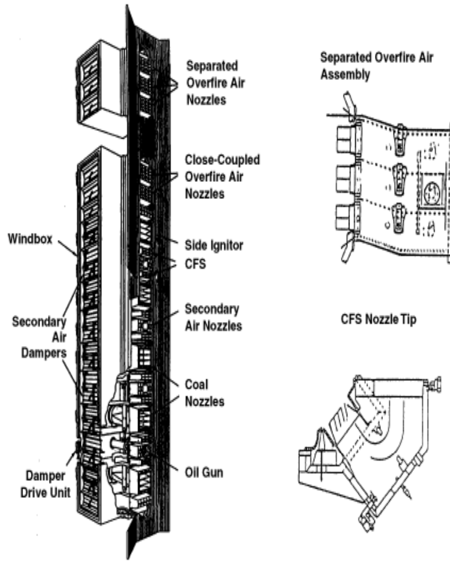

FIGURE 2: TYPICAL ALSTOM LNCFS™ DESIGN ARRANGEMENT (LNCFS™ III SHOWN)

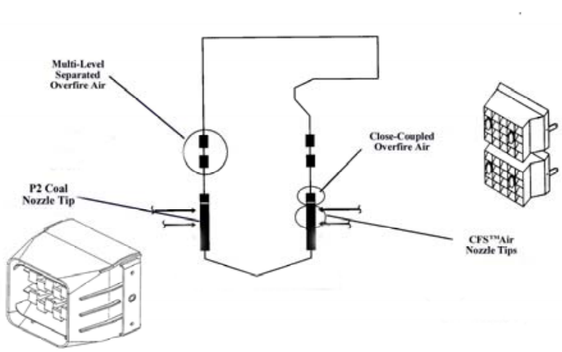

FIGURE 3: SCHEMATIC OF TFS2000™R FOR A BITUMINOUS COAL USING P2 COAL NOZZLE TIPS

The main design parameters of the OFA system are based on the target post-retrofit emissions levels, furnace configuration, heat input, fuel characteristics and pre-modification operating conditions. A unique feature of ALSTOM's overfire air design is its patented horizontal yaw adjustment. The manually adjustable yaw enables each overfire air jet to be independently directed to maximize mixing during the final combustion process in order to minimize potential increases in carbon monoxide emissions. It is not a control system function, but a manual adjustment that is permanently set during the commissioning phase of each LNCFS™ system retrofit project. The exception to this is the VCCOFA or Vaned CCOFA used in the LNCFS™P2 system. VCCOFA does not tilt or yaw and maximizes the amount of flow in the given opening as well as aerodynamically directs the air away from the fuel to maximize separation and NOx reduction. A schematic of a VCCOFA compartment is shown in Figure 4.

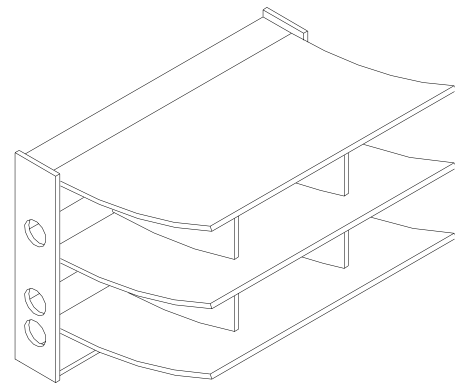

FIGURE 4: SCHEMATIC OF VCCOFA ARRANGEMENT

"FLAME FRONT CONTROL" COAL NOZZLE TIPS

Another important feature of NOx control utilized in the LNCFS™ and TFS 2000™ R system designs is early fuel devolatilization within an oxygen-deficient environment. With conventional firing systems, coal is devolatilized in an oxygen-rich environment and the fuel nitrogen released can readily react with the available oxygen to form nitrogen oxide compounds. With the LNCFS™ and TFS 2000™ R systems, rapid coal devolatilization is accomplished by establishing a flame front near the exit of the coal nozzle tip. Besides the NOx emissions control benefits, establishing coal ignition early in the combustion process improves flame stability and minimizes increases in unburned carbon levels post-low NOx retrofit. Figure 5 shows an LNCFS™-P2 coal nozzle tip, which is specifically designed for low NOx firing applications. For each low NOx system installation, site-specific coal nozzle tip design configurations are provided based on existing flame characteristics, coal constituents and characteristics, fuel line transport conditions, and other historical operating factors.

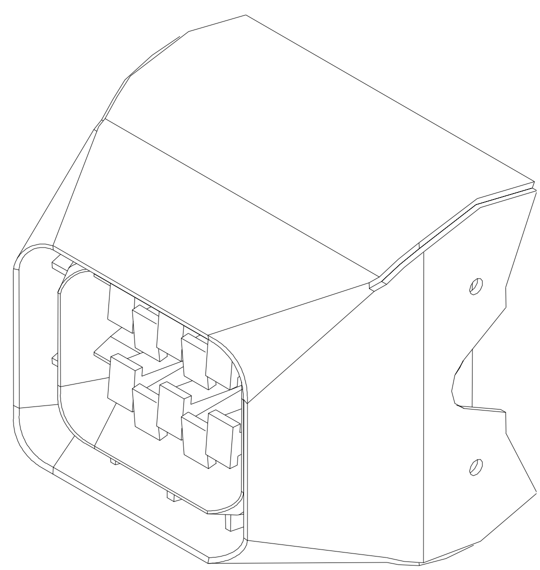

FIGURE 5: LNCFS™ P2 COAL NOZZLE TIP

CFS™ CONCENTRIC FIRING SYSTEM

CFS™ concentric firing is a patented staging technique in which a portion of the secondary air is directed away from the fuel streams toward an imaginary circle that is concentric with the main firing circle. Offsetting some of the secondary air further reduces the local firing stoichiometry during the initial combustion stages. Figure 6 illustrates the relative directions of the coal and air streams with the LNCFS™ arrangements. The offset air is introduced into the furnace through CFS™ air nozzle tips. Depending upon specific unit requirements, horizontally adjustable CFS™ air nozzle tips may be provided. An added benefit of the CFS™ design is that the offset air maintains an oxidizing boundary layer along the furnace waterwalls. This decreases lower furnace waterwall slagging and other potential problems associated with operating under reduced burner zone stoichiometric firing conditions.

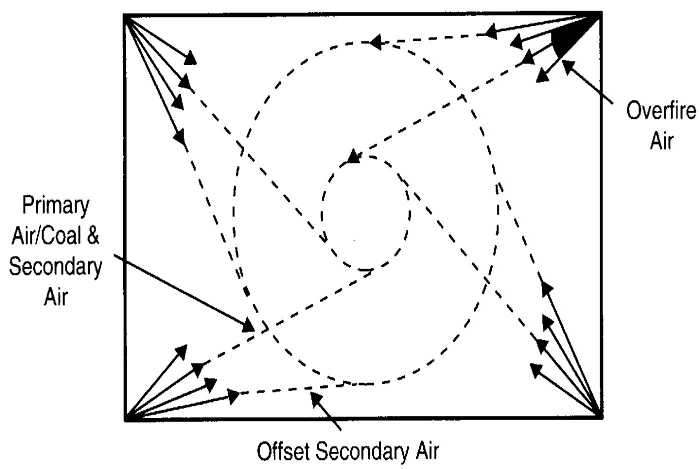

FIGURE 6: DIRECTION OF COAL AND AIR STREAMS IN LNCFS™ DESIGNS

TFS 2000™ R SYSTEM DESIGN

The design philosophy of the TFS 2000™ R firing system is based on the integration of precise furnace stoichiometry control, pulverized coal fineness control, initial combustion process control, and concentric firing via CFS™. This represents the most versatile in-furnace combustion NOx control system. Multiple levels of 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.

ALSTOM LOW NOx FIRING SYSTEM OPERATIONAL EXPERIENCE

ALSTOM has designed and supplied over 215 low NOx retrofit systems for tangentially fired coal units. The population includes all four LNCFS™ configurations, as well as TFS 2000™ R systems. The retrofitted units range in size from 44 MWe industrial boiler to a 900-MW supercritical, divided unit. The retrofit experience covers an extensive range of coal types from lignites to bituminous.

Figure 7 illustrates MCR NOx reduction experience with Level I installations as compared to unit size represented by MCR MWe. Figures 8, 9, and 10 provide similar data with respect to Level II, Level III, and TFS2000™ R installations, respectively. The figures generally illustrate the effectiveness of LNCFS™ technology over a wide range of boiler sizes. It is important to remember direct correlations between NOx emissions and unit size are not possible, as a variety of other parameters such as coal type, furnace design, and operating conditions affect NOx.

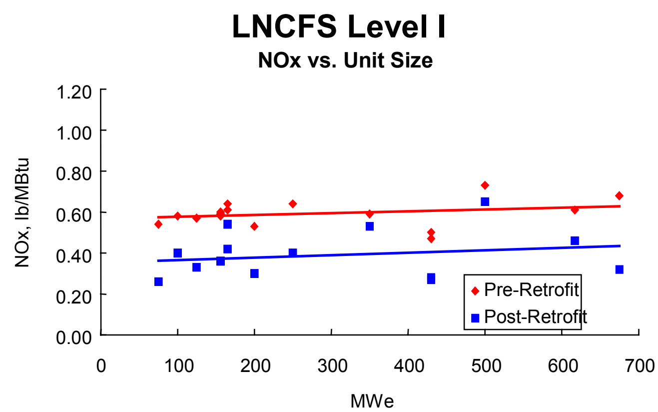

FIGURE 7: LNCFS™ LEVEL I – NOx VS. UNIT SIZE

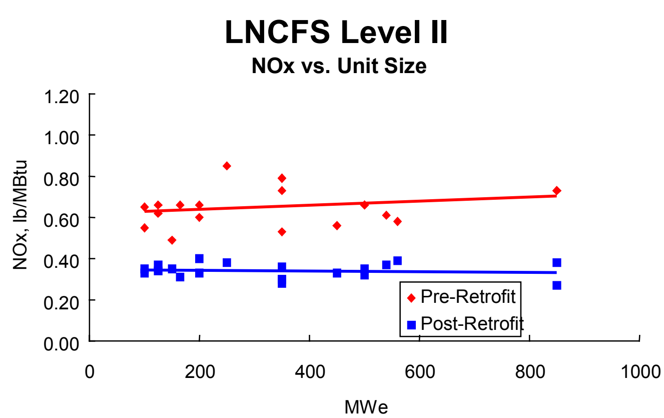

FIGURE 8: LNCFS™ LEVEL II – NOx VS. UNIT SIZE

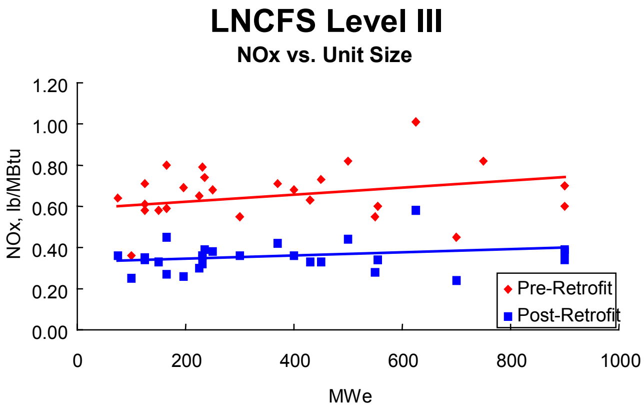

FIGURE 9: LNCFS™ LEVEL III – NOx VS. UNIT SIZE

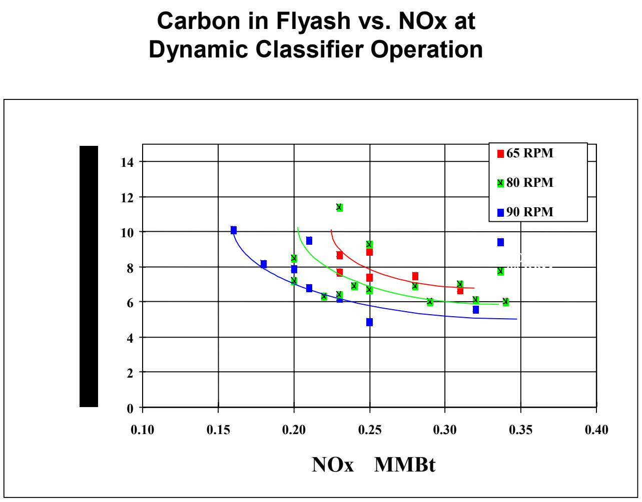

FIGURE 10: TFS2000™R NOx AND UNBURNED CARBON RESULTS WITH AN EASTERN BITUMINOUS COAL

Other results regarding LNCFS™ and TFS2000™R installations including unburned carbon, furnace design, coal factors and boiler performance may be found in References 3, 4, 5, 6, 7 and 8. In general, the following conclusions can be made:

- 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 reduction efficiency of any low NOx firing system is highly dependent upon a number of fixed site specific parameters. Unit design parameters such as furnace size, height, and heat release rate all influence NOx formation. Operational variables such as unit loading (base loaded, dispatch loaded, etc.) and control system flexibility and response capability also effect NOx. As stated earlier, there is a wide variety of unit designs and permutations of these variables in the existing boiler population, and that is the reason ALSTOM developed a family of low NOx firing systems.

Above all else, coal type is generally the single most significant variable impacting NOx emissions.

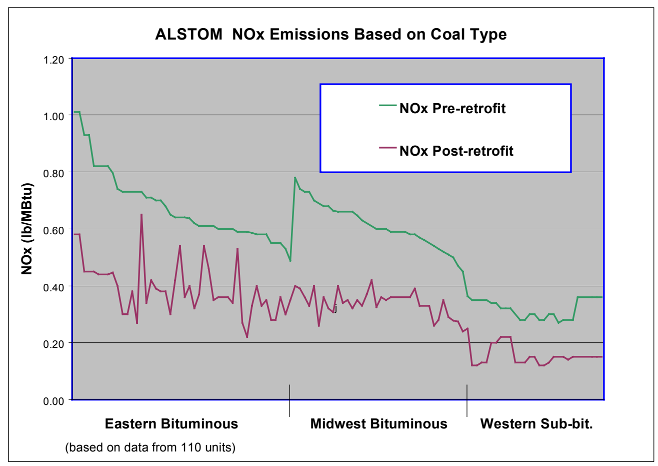

FIGURE 11: LOW NOx FIRING SYSTEM PERFORMANCE BASED ON COAL TYPE

Figure 11 shows historical data of pre and post retrofit NOx emission from 110 tangentially-fired units retrofitted over the past ten years. The data includes examples of all of the Low NOx systems provided by ALSTOM. As can be seen, there is a general trend that the more reactive the fuel, the lower the NOx emission that can be achieved. However, even this is not an absolute rule as can be seen from the spikes and dips in the data trend.

ALSTOM's operating data does show that the highly reactive fuels are producing the lowest NOx emissions in the US. The US Environmental Protection Agency (EPA) publishes data on their internet website listing all generating stations and their yearly NOx emission averages. In 2001, the most recent year data is available in this format, the figures showed that 19 of the top 20 lowest emitting pulverized coal fired units in the US fired highly reactive Powder River Basin (PRB) coal, and were equipped with ALSTOM Low NOx firing systems. This data is illustrated in Figure 12. NOx values are presented as lbs/Mbtu.

Performance Projects
Low NOx Capabilities ALSTOM

EPA data for 2001 reveal that 19 of the 20 lowest emitting coal units use Alstom-supplied low NOx Firing systems

No	Unit	State	NOx	System	No	Unit	State	NOx	System
1	Polk	FL	0.10	CGCC*	11	Baldwin 3	IL	0.14	TFS 2000
2	Labadie 1	MO	0.11	LNCFS	12	Parish 7	TX	0.14	TFS 2000
3	Labadie 2	MO	0.11	LNCFS	13	Joppa 1	IL	0.15	LNCFS
4	Labadie 3	MO	0.11	LNCFS	14	Joppa 2	IL	0.15	LNCFS
5	Labadie 4	MO	0.11	LNCFS	15	Joppa 3	IL	0.15	LNCFS
6	Joliet 29 - 71	IL	0.12	TFS 2000	16	Joppa 4	IL	0.15	LNCFS
7	Joliet 29 - 72	IL	0.12	TFS 2000	17	Joppa 5	IL	0.15	LNCFS
8	Rush Island 2	MO	0.12	LNCFS	18	Joppa 6	IL	0.15	LNCFS
9	Waukeegan 8	IL	0.13	TFS 2000	19	Newton 1	IL	0.15	LNCFS
10	Rush Island 1	MO	0.13	LNCFS	20	Newton 2	IL	0.15	TFS 2000

*Coal Gasification Combined Cycle demonstration unit

FIGURE 12: US EPA DATA: LOWEST AVERAGE YEARLY NOx EMISIONS (COAL) FOR 2001

The above data shows that even though the TFS2000™R is the most aggressive of ALSTOM's low NOx firing systems, it is not necessarily required to achieve the lowest NOx levels. As stated earlier, ALSTOM's approach to developing low NOx solutions is to evaluate all of the pertinent factors for a given project and develop the most effective solution for the Client.

WATERWALL WASTAGE EXPERIENCE

Of the over 215 retrofit LNCFS™ and TFS 2000™ R low NOx burner systems for tangentially fired boilers, more than 150 units have at least two years of post-retrofit operating experience. It has recently been reported that approximately 5% of these units have observed accelerated waterwall wastage following retrofit with LNCFS™ Level III systems only. All but one of the reported cases represents divided wall (eight corner) units with certain wastage precursor criteria in common. ALSTOM's principal conclusion is that units which demonstrate any increased potential for waterwall wastage, post-low NOx retrofit, have some or all of the following characteristics: prior history of wastage, coal with high sulfur content, high furnace heat release rate, and divided furnace design.

RECENT TECHNOLOGICAL ADVANCES

As market demands change, new advances are needed. ALSTOM has development activities in a wide variety of areas as a result. For example, as emission targets drop, the need to more accurately predict emissions increases. To meet this need for improved performance prediction, neural network models are being developed. The traditional method is to use multiple linear regression models to fit empirical data. The benefit of using a neural network-based model is that the prediction accuracy improves with each new data that it receives.

A second fundamental aspect of improving predictions is accuracy of measurements. ALSTOM is continuing to develop and implement coal devolatization models to predict volatile matter yields in a pulverized coal-fired boiler that are at least the same and usually higher than those measured by ASTM standards. This represents a significant improvement in the modeling of coal combustion and the ability to accurately fundamentally predict the products of combustion, including flyash carbon levels.

The study of coal fundamentals continues to advance. Kinetic parameters can now be selected on a surrogate basis and used in conjunction with computational fluid dynamics coal combustion models.

There continues to be many improvements in the area of coal nozzle tips. Coal nozzle tips are traditionally considered to be consumable items since they see extreme temperature and wear environmental conditions, which prevents them from lasting more than a few years. ALSTOM is currently investigating the use of advanced materials, such as ceramics, to better withstand oxidation, thermal fatigue and wear. This, combined with design optimization, has the potential of doubling the life of the coal nozzle tip.

One of the most recent areas of development is the Fuel / Air Balancing (FAB) system. As NOx emission targets are being pushed lower and lower, it becomes necessary to enhance the unit control for every possible NOx reduction. By accurately measuring and controlling the fuel and air flows to each individual burner, it is possible to achieve additional NOx reductions from existing systems. New products are currently under development at ALSTOM and are being field tested in US utility boilers to reliably achieve this fine level of control.

LOW NOx RETROFIT ECONOMICS

There is generally a range of technically feasible options for a single unit compliance plan. The challenge is to balance the cost, performance and impact on unit operation for the best overall result. This effort becomes much more difficult on a system-wide basis as the matrix of choices expands. However, if this evaluation is done systematically, opportunities exist for the greatest cost savings through the optimization of low-cost systems and elimination of redundant or overcompliant equipment.

The basic choices for any particular unit are:

A. Firing systems tuning and/or basic modifications

B Aggressive firing system modifications, possibly including SOFA systems, pulverizer and control system modifications

C. SCR addition

D. Combination of any of the above choices

The options above are listed in increasing order of NOx reduction efficiency and corresponding cost. Option A can be done at a relatively low cost, and in most cases can be expected to provide a modest reduction in NOx emissions. However the cost effectiveness of this is very attractive, and in most cases is a cost effective addition to any compliance plan. Option B, which also incorporates Option A, represents a moderate cost investment and a significant NOx reduction. In some cases, this option may be sufficient to satisfy the mandated emission limits. Option C will in most cases reach the mandated NOx targets albeit at a substantial capital and operating cost. Option D, while having the highest capital cost of all alternatives, may provide the most economic long-term solution by reduci ng overall operating costs of the SCR.

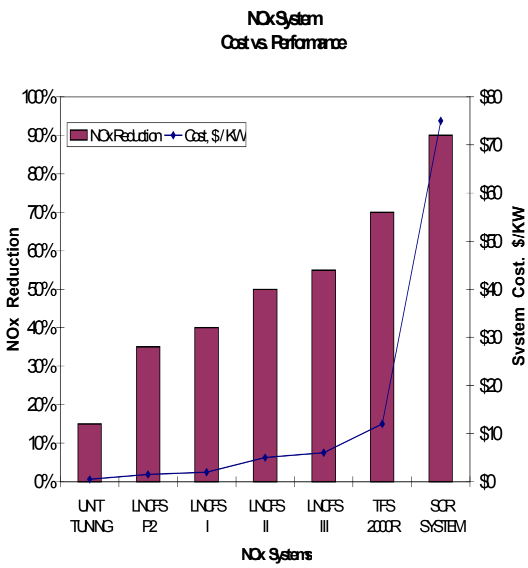

FIGURE 13: NOx REDUCTION SYSTEM COST VS PERFORMANCE

The relative costs and reduction efficiencies of the alternatives presented above are illustrated in Figure 13. These costs are based upon a 200 MW unit, with an average degree of difficulty for installation of the retrofit systems. Actual costs for any unit are highly dependent upon site specifics such as fuel fired, unit configuration, equipment interference, and available space.

CONCLUSION

The final cost of NOx emission compliance is impacted by many site specific and regulatory variables, some of which are still undefined. Governmental regulations are being challenged on a technical and legal basis, and as such are subject to change. Regardless of the final outcome of the emissions regulations, there will be no simple across-the-board solution for all units. Each generating system will have to be evaluated based on its unique characteristics to determine the combination of NOx reduction techniques that will provide the optimum low cost, efficient and reliably operating generating network.

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