Assessment of Current and Advanced NOx Control Technology for Coal-Fired Utility Boilers*

by

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INTRODUCTION

NOx is the remaining major or criteria pollutant that has not been effectively reduced to emission levels approaching 10% or less of those from an uncontrolled stationary combustion source. This is particularly true at the present in coal-fired utility boilers because of the conversion of fuel-bound nitrogen in the coal to NO during the combustion process. However, coal is our largest natural fossil fuel resource and DOE is responsible for developing methods of utilizing coal in an environmentally acceptable manner. An important factor in meeting future energy needs and achieving national energy independence is our ability to expand the use of coal in electrical power generation. Consistent with its responsibilities, EPA has established research goals for NOx emissions with coal of 200 ppm by 1980 and 100 ppm by 1985. If it is eventually shown that comparable levels are necessary to maintain air quality standards and cost-effective methods exist, then the likelihood of more stringent new source performance standards (NSPS) in the mid-1980's exists for coal-fired utility boilers.

For the reasons outlined above, a need existed to conduct a comprehensive state-of-the-art review of all potential combustion modification methods for NOx control on coal-fired units. Combustion modification has in the past been the most cost-effective approach to limiting NOx formation and emissions. With the emergence of selective gas-phase NOx decomposition methods, it was desirable to also conduct a review of the most recent developments in that field.

NOx FORMATION

Control of NOx formation during coal combustion is particularly difficult because nitrogen-bearing compounds in the coal are oxidized in the initial stages of the flame zone to produce "fuel nitrogen NOx". Important parameters in this process are local stoichiometry, temperature, and the residence time at these conditions plus the mixing conditions for supplemental air addition and carbon burnout.

Combustion modifications also influence the formation of "thermal NOx" at high combustion temperatures due to the thermal fixation of nitrogen and oxygen in the combustion air. Important parameters that affect peak flame temperature are local oxygen availability, fuel-air mixing patterns, the presence of heat absorbing inert combustion products, combustion air preheat, local heat transfer to adjacent cooled surfaces, etc. Both burner and furnace design are very important factors in total NOx emissions since they influence both thermal and fuel-related NOx.

*This study was conducted for Argonne National Laboratory under Contract 31-109-38-3726 as part of an ongoing program, Environmental Control Implications of Coal Utilization for Power Generation, being conducted in turn for DOE.

NOx CONTROL METHODS

One of the purposes of the study was to not only summarize the technical performance of various NOx control methods, but also to point out and quantify some of the more important operational constraints associated with these methods. The study was primarily concerned with the following control methods and operational concerns.

Methods (or Factors)	Concerns
Low excess air	Cost of combustion modifications
Staged combustion	Furnace wall corrosion
Flue gas recirculation	Tube wall erosion
Combination methods	Carbon carryover
Coal type - bituminous/ subbituminous	Combustion stability
	Load restrictions
Boiler design - wall fired, tangential, cyclone	Secondary pollutants
	Energy penalties
Burner design - conventional, low-NOx, advanced concepts	Retrofit applications
	Impact on auxiliary equipment
	Operation and maintenance

Available NOx emissions test program data was examined for the most prevalent boiler designs and the effectiveness of various combustion control measures is summarized in Table 1. The control method having the largest NOx reduction potential (short of reburnering with new low-NOx burners) was staged combustion, accomplished either by removing burners from service or by the use of overfire air (driving the remaining in-service burners fuel-rich). In the NOx Assessment Final Report (1) for Argonne National Laboratory, NOx reduction potential summary graphs were prepared for each of the various control methods. Although space limitations preclude showing all of this supporting data used in the preparation of Table 1, some examples for burner-out-of-service operation are shown in Figures 1, 2, and 3.

It should be emphasized that there are large unit-to-unit variations in coal-fired utility boiler NOx emissions, even within the same boiler design type. This is due to varied boiler geometry with size, age, and coal type. Boiler operating practice, maintenance, pulverizer settings, and coal characteristics often vary from plant to plant even within the same utility. Frequently a plant in the northeastern U.S. may obtain coal simultaneously from two or three sources. Therefore, it is not unusual to see baseline NOx emissions vary by as much as 500 ppm for a given boiler type (e.g., horizontally opposed fired). Because of this wide variation in baseline emissions, it frequently is more convenient to express the effectiveness of a given NOx control in terms of a potential percentage NOx reduction as in Table 1 and Figures 1 through 3. However, it is also recognized that many utility and government groups are interested in the lowest attainable "state-of-the-art" NOx emission levels as summarized in the table below.

STATUS OF COAL-FIRED UTILITY BOILER NOx CONTROL TECHNOLOGY
FOR NEW UNITS AND RETROFIT APPLICATIONS

	Lowest Attainable NOx Emission Levels			
	New Units		Retrofit	
	ppm at 3% O_2	lb/MBtu	ppm at 3% O_2	lb/MBtu
Wall-Fired				
Single Face Fired	300-350	0.45	400-500	0.6
Horizontally Opposed	300-350	0.45	400-600	0.6
Tangential	250-300	0.45	250-350	0.4

For new units, these emission levels are based on the most recent low-NOx burner designs (e.g., dual register configurations or overfire air on tangential units) frequently employed in combination with a compartmentalized windbox and liberal furnace volumes. Retrofit emission levels shown can be reached by reburnering or in some cases by carefully applied staged combustion firing modes. Although it is currently possible to attain these NOx levels with some consistency, this does not mean that all existing units can be modified to these levels regardless of boiler age, design, coal type, etc.

OPERATIONAL CONSIDERATIONS

Previous assessment studies have not properly evaluated the numerous operational factors that are of major importance to the user in selecting and implementing a combustion modification technique. Five major topic areas were examined as part of the current study:

1. Problems in design, installation, operation and maintenance of a NOx control technique
2. Applicability of a given technique for retrofit
3. Impact of low NOx modes on other pollutants
4. Effect of NOx control techniques on the performance of auxiliary equipment
5. Possible energy penalties associated with implementation of a given method

Some of the more important conclusions are outlined below by control method.

A. Operational Factors - Low Excess Air and Staged Combustion--

- Low excess air operation is possible with NOx reductions of up to 15% and a boiler efficiency improvement if careful attention is paid to combustion uniformity in the burner region. Reductions of 35% are possible with staged combustion.
- Close control of local and overall air/fuel ratio and rigorous combustion equipment maintenance is essential to the success of both methods.
- Overfire air port configurations or burner patterns resulting in flame impingement and potential tube wall corrosion must be avoided.
- New designs should incorporate adequate pulverizer and fan capacity to accommodate low NOx modes. Conservative windbox, furnace and convective section designs are recommended.
- Carbon carryover and particulate loadings are no greater than normal operation if the excess air is properly established and maintained (as required) for all loads, fuel types, and boiler conditions.
- No significant increase in secondary pollutants or impact on auxiliary equipment has been noted but more data is needed.

B. Operational Factors - Flue Gas Recirculation--

Flue gas recirculation was found to be a relatively unattractive NOx control method for some of the reasons listed below (2):

- NOx reductions of 15% or less do not compare favorably with reductions of 25% to 35% with staged combustion (20% of the burners out of service).
- A measurable efficiency penalty occurs (approximately 0.5%) with flue gas recirculation due to the auxiliary load of the fans.
- Potential problem areas include tube erosion, flame stability, fan vibration, and increased maintenance.

C. Operational Factors - Corrosion, Slagging and Fouling--

Staged combustion and low excess air operation are the most attractive techniques for NOx control but the major unresolved issue concerns whether these operating modes with fuel-rich burner combustion zones tend to accelerate boiler tube wall corrosion. Because of the importance of this possible deterrent, a major subsection of the final report was devoted to this topic.

Since the more widespread application of low NOx operating modes tends to hinge on this issue, the "facts" concerning corrosion tend to be in a state of dispute but some of the more important observations and recent findings are outlined below:

- High temperature fire-side corrosion of water walls in the radiant section of pulverized coal-fired boilers is generally confined to areas of flame impingement and/or slag buildup.
- The slag deposit on a relatively cold tube wall is usually coupled to a locally reducing atmosphere caused by flame impingement.
- Two types of corrosive attack have been identified in boilers firing coals with appreciable sulfur content; alkali iron bisulfate and iron sulfide modes of attack. The sulfate-type attack predominates over the sulfide type.
- Deposits found on corroded tubes often possess high alkali content, high SO_3 content, and high water solubility. Deposits frequently are pale, bluish white with a glossy "enamel" appearance.
- Slagging, fouling, and corrosion problems have frequently been solved in the past with maintenance or adjustments to the pulverizer, coal distribution pipes, and enforced replacement schedules for the burner impellers.
- Numerous corrosion measurements in low NOx operating modes have been made in the past with air-cooled corrosion probes. These short term tests raise many questions concerning the validity of this technique. More extensive long-term tube-panel tests are necessary to resolve corrosion concerns.

COST OF COMBUSTION MODIFICATIONS

One of the most important factors in addition to NOx reduction effectiveness and operational limitations from the utility operator's standpoint is the cost of combustion modifications. Numerous cost analyses have been conducted under EPA sponsorship for new units and retrofit applications including those by Combustion Engineering (3) and A. D. Little (4). Total costs have been broken down by annual capital, operational, and fuel costs. The relative cost effectiveness of NOx emissions control on a 600 MW coal-fired unit is shown in Figure 4. With current technology, the cost effectiveness rapidly becomes unattractive at emission levels approaching 0.4 lb/MBtu.

ADVANCED NOx CONTROL CONCEPTS

The two most promising advanced NOx control concepts now undergoing research and development are the selective gas-phase NOx reduction flue gas treatment systems and new advanced burner/boiler designs.

Studies by Exxon and KVB have demonstrated NOx reductions up to 90% when ammonia is injected into flue gas streams in the vicinity of 1750 °F. Laboratory-scale feasibility tests with ammonia injection for coal applications has shown that 50% to 80% NOx reductions are possible for the coals tested. Full scale commercialization studies are currently underway and the possibility of a full scale utility boiler demonstration test in the next two or three years is very likely.

Advanced burner/boiler design concepts have concentrated on combustion methods that will minimize the conversion of fuel-bound nitrogen to NOx. Based on recent laboratory and subscale tests at EPA and EPRI contractor's facilities, the attainment of EPA's research goals of 200 ppm by 1980 and 100 ppm by 1985 are very likely.

This does not mean that all operational problems will be solved and production units will be available by that time. However, recent research programs at B&W, KVB, Aerotherm, and EER are establishing the proper stoichiometry, temperature, and residence times necessary to limit NOx formation to less than 200 ppm in these initial stages of direct coal combustion. Research is continuing into more complex problems of secondary air addition, carbon burnout, and containment of fuel-rich combustion conditions without extensive materials corrosion problems.

In conclusion, continued progress is being made to reduce NOx emissions from direct coal combustion through low NOx burner designs, currently capable of limiting emissions to 0.6 lb/MBtu and research designs expected to meet approximately 0.25 lb/MBtu emission goals by 1980.

REFERENCES

1. Thompson, R. E., Sonnichsen, T. W., Shiomoto, G. H., and Muzio, L. J., "Assessment of NOx Control Technology for Coal-Fired Utility Boilers," KVB Report 16400-709, September 23, 1977.

2. Thompson, R. E. and McElroy, M. W., "Effectiveness of Gas Recirculation and Staged Combustion in Reducing NOx on a 560 MW Coal-Fired Boiler," EPRI FP-257, September 1976.

3. Blakeslee, C. E. and Selker, A. P., "Program for Reduction of NOx from Tangentially Coal-Fired Boilers, Phase I," EPA 650/2-73-005, August 1973.

4. Standard Support (EIS Vol. 1), EPA 450/2-76-030a, 1977.

TABLE 1. COMBUSTION MODIFICATION ASSESSMENT SUMMARY

	Control Method					
	Low Excess Air	Biased Firing	Burners Out of Service	Overfire Air	Flue Gas Recirculation	New Burners
Basic Mechanism of Control	Increase fuel/air ratio at all burners	Increase fuel/air ratio to majority of burners	Increase fuel/air ratio to active burners	Increase fuel/air ratio to burners by diverting combustion air	Reduce peak flame temperature	Controlled diffusion flame
NOx Reduction Potential						
Single Face Fired						
Typical	0-15%	5%	30%	15%	--	--
Maximum	15%	7%	35%	30%	--	--
Horizontally Opposed Fired						
Typical	0-15%	5%	25%	30%	14%	30%
Maximum	15%	8%	35%	58%	17%	60%
Tangentially Fired						
Typical	0-10%	--	30%	30%	--	--
Maximum	10%	--	45%	35%	--	--
Modification Cost ($/kW) New/Retrofit						
Single Face Fired	~ 0/0.64	--	--	0.2/0.75	--	--
Horizontally Opposed Fired	~ 0/0.64	--	--	0.2/0.75	--	--
Tangentially Fired	--	--	--	0.2/0.75	--	--
Primary Limitations	Slagging, smoke, flame instability	Degree of biasing wall slagging and corrosion	Degree of staging, wall slagging and corrosion	Degree of staging, wall slagging and corrosion	Much less cost effective than staging	Cost
Limiting Factors In Effectiveness	Carbon carryover	Carbon carryover, flame stability, smoke	Carbon carryover, flame stability, smoke	Carbon carryover, flame stability smoke	Flame stability	Windbox configurations, flame stability
Retrofit Limitations	Combustion controls and instrumentation	Pulverizer and fan capacity, flexibility in coal feed system	Pulverizer and fan capacity, flexibility of coal feed system	Furnace configuration, fan capacity	Unit layout, fan capacity	Furnace and windbox configuration, fan capacity
Energy Penalties	May increase slightly	None	None	None	0.5% due to auxiliary fan loadings	None
Secondary Pollutants	No effect*	No effect*	No effect*	No effect*	No effect*	No effect*
Operational and Maintenance Considerations	Additional combustion controls, increased maintenance	Additional combustion controls, increased maintenance	Additional combustion controls, increased maintenance	Additional combustion controls, increased maintenance	Tube erosion, fan vibration, increased maintenance	Minimal
Impact on Auxiliary Equipment	None	None	None	None	Increased fan loading	None reported

*Based on limited available data

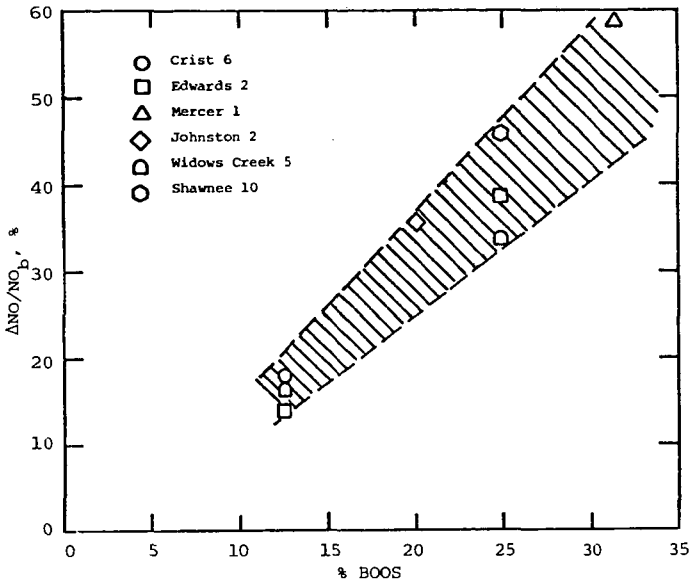

Figure 1. NOx reduction potential of BOOS for single face-fired units.

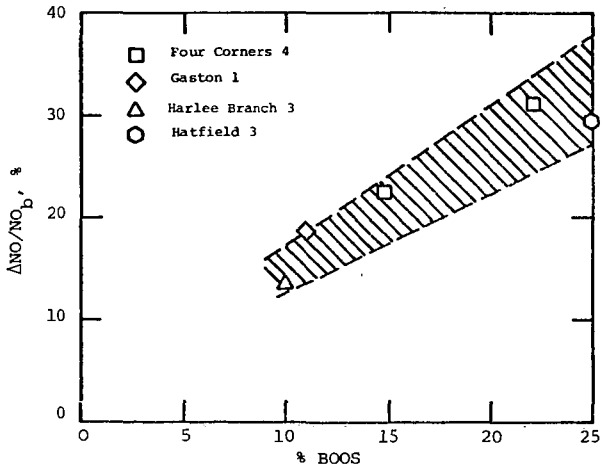

Figure 2. NOx reduction potential of BOOS for horizontally opposed units.

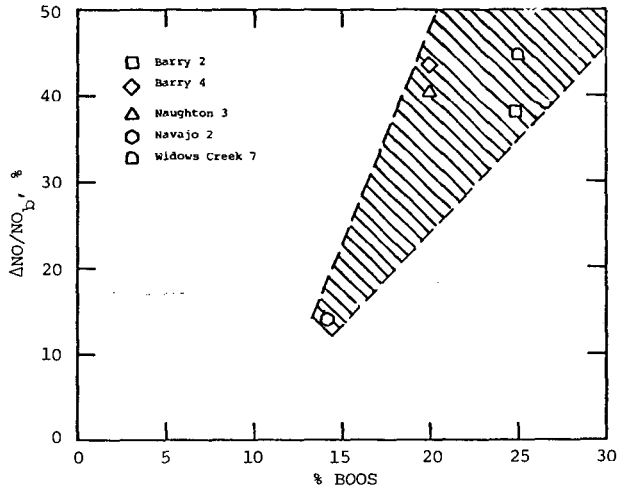

Figure 3. NOx reduction potential of BOOS for tangentially fired units.

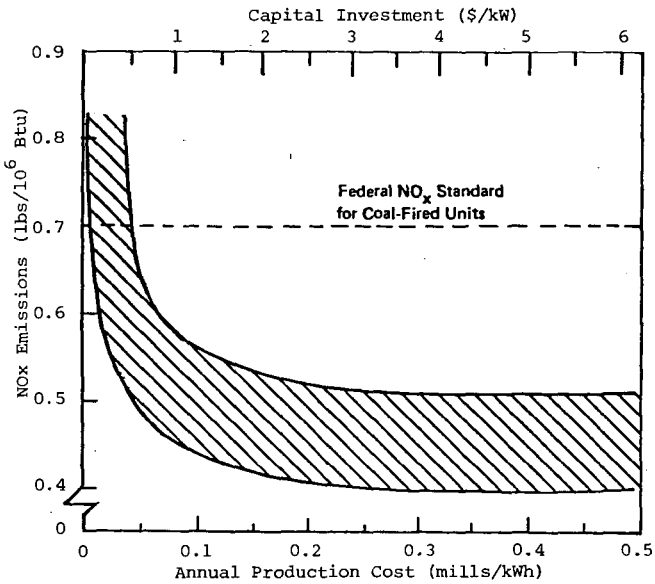

Figure 4. Cost effectiveness of NOx emissions control of a 600 MW steam electric generator (4).