United States
Environmental Protection
Agency

Air and Energy Engineering
Research Laboratory
Research Triangle Park, NC 27711

Research and Development

EPA/600/S7-89/015 May 1990

EPA

Project Summary

Field Evaluation of Low-Emission Coal Burner Technology on Utility Boilers

A.R. Abele, J. F. LaFond, J.A. Cole, G.S. Kindt, W.C. Li, E. C. Moller, R. Payne, and J. L. Reese

This report summarizes an extensive field evaluation of low-emission coal burner technology on utility boilers. The experimental studies described fall into four main areas:

- **Distributed Mixing Burner (DMB) Evaluation--in which a prototype DMB and two commercial Babcock & Wilcox burners were tested at scales of 60 and 120 x 10^6 Btu/hr (17.5 and 35 MW) in a large experimental test furnace. The evaluation focused on combustion performance, NO_x emissions, and the application of sorbent injection for SO_2 control.**
- **Second Generation Low-NO_x Burners--in which the performance of three 78 x 10^6 Btu/hr (22.9 MW) Babcock & Wilcox low-NO_x burners was evaluated and optimized. Key performance criteria included NO_x emissions, flame length, and combustion efficiency. Results from these tests were used to recommend a burner for application in the EPA LIMB (Limestone Injection Multistage Burner) demonstration program at Edgewater Station Unit 4.**
- **Field Evaluations--in which field testing was performed at two different utility boiler sites. The objective of this testing was to compare commercial burner performance under field and test furnace conditions, as a basis for the scaling of NO_x emissions.**
- **Alternate concepts--in which experimental studies were conducted on coal-fired precombustor concepts, with a view to the simultaneous control of NO_x, SO_2, and particulate emissions. This activity included fundamental studies of parameters affecting sulfur evolution and retention by injected sorbents under fuel-rich slagging conditions.**

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in five separate volumes of the same title (see Project Report ordering information at back).

Introduction

The objective of this program was to evaluate the performance of the EPA Distributed Mixing burner (DMB), incorporating Babcock & Wilcox (B&W) burner hardware, in a utility boiler. The original plan to achieve this objective involved four key elements:

1. A field test of the host boiler with the original burners to establish the "baseline" burner/boiler performance.
2. A test of the original, "baseline" burner in the Large Watertube Simulator (LWS) research furnace to calibrate the furnace against the corresponding host boiler.
3. Evaluation and optimization of a prototype DMB with B&W

components in the LWS to verify performance prior to installation at the host site.

4. Long-term field evaluation of the DMB in the host boiler.

Progress on this plan was delayed because of difficulties in finding a suitable host boiler. Costs to fully retrofit a utility boiler with DMBs escalated beyond available funding. A revised program scope addressed two distinct issues. The major portion of the program still focused on the evaluation of the DMB for utility boiler application. The second area of interest added to the scope of this project was an evaluation of alternate concepts for low-NO_x emissions coupled with high levels of particulate removal and possible SO_x control. These alternate concepts considered fuel-rich, high-temperature prechambers, such as cyclone furnaces. The alternate concept program was structured to: (1) compile and synthesize existing data on coal-fired precombustor systems; (2) conduct initial pilot scale tests at 1 x 10^6 Btu/hr (293 kW) to identify the key parameters affecting NO_x and SO_x reduction potential, and (3) a second phase of more fundamental testing structured to investigate a broader range of SO_x control issues in smaller, well-controlled experiments to generate a more complete set of basic precombustor design data.

The evaluation of the DMB for utility boiler application was restructured to achieve the program objective without a field installation. In the original program plan, differences In performance with the DMB were to be determined by direct comparison to the original equipment burners. The elimination of the field installation precluded this comparison and required dependence on research furnace test results. As part of the revised program, the performance of the prototype DMB in the LWS research facility had to be demonstrated to be similar to the performance in a field operating boiler.

The scope was further expanded with an opportunity to directly participate in full application of second generation low-emission burners to an operating boiler. The EPA demonstration of LIMB (Limestone Injection Multistage Burner) technology had the objective of reducing both NO_x and SO_2 emissions by 50%. The NO_x reduction was to be achieved by retrofitting existing burners at Ohio Edison's Edgewater Unit 4 boiler with second generation low-NO_x burners. Because of the constraints at this boiler, evaluation of three candidate B&W burners prior to selection was essential.

The broad scope of this program can be thus separated into four distinct parts: (1) the evaluation of prototype DMBs for application to utility boilers; (2) field tests of baseline burners at two host boilers to support the extrapolation of prototype DMB performance to field applications; (3) evaluation of three B&W second generation low-NO_x burners to be selected for use in the EPA LIMB demonstration; and (4) alternate concepts for NO_x and SO_x control in precombustors. Each of these represents a distinct element of the program. The final report is, therefore, organized to fully address each element.

Volume I--Distributed Mixing Burner Evaluation. Volume I presents the results from the prototype DMB evaluations in the LWS, the principal element to achieve the original program objectives. This part describes the methodology employed to evaluate the DMBs without a field retrofit, linking research furnace results to operating boilers. The experimental systems, including test burners, fuels, the test facility itself, and testing procedures, are fully detailed. Burner performance for each test burner is discussed. The key to interpreting the results is the link of the LWS test results to operating utility boilers achieved with tests of commercial B&W burners in the LWS and field test results of the same burner design in utility boilers. This link allows extrapolation of prototype DMB performance from the LWS to the field. A summary of sorbent injection trials for SO_2 control is also included in Volume I to broaden the existing data base and experience with LIMB technology.

Volume II--Second Generation Low-NO_x Burners. Volume II summarizes the LWS trials of the three B&W low-NO_x burners being considered for the EPA LIMB demonstration program at Edgewater Station Unit 4. The three burners were: the Dual Register burner (DRB), Babcock-Hitachi NR burner (HNR), and the B&W XCL burner. The burners and each configuration tested are described, along with the fuels and test facility configuration used throughout these tests. The optimization of the various configurations of each basic burner design is described with respect to the key performance criteria of NO_x emissions, flame length, combustion efficiency, and burner pressure drop. The performance of each optimized configuration is compared to the LIMB demonstration site requirements and recommendations for burner selection are made. Finally, sorbent injection test were conducted for a selecte configuration of each burner design These tests were performed to determin any possible effect of burner design o SO_2 capture potential with sorben injection.

Volume III--Field Evaluations. Volum III details the field tests performed i conjunction with the DMB evaluation. Th field tests were performed at two differen utility boilers, generally similar in desig and size except for the burne equipment. Comanche Unit 2 of Colorad Public Service was equipped with B&V Circular burners, the pre-NSPS (Ne Source Performance Standard) burne design. The Wyodak Plant of Black Hill Power was equipped with DRBs. Tes results of emissions and boile performance are presented for each uni Key performance aspects from these tw boilers are used in interpreting LWS test of the Circular burner and the DRB.

Volume IV--Alternate Concepts. Pre combustor studies for NO_x and SO control are described in Volume IV. Thi work represents alternate concept considered as a result of the program' restructuring. Volume IV stresses th fundamental design considerations fc precombustor control of SO_2 emission with a brief summary of pilot scale, 1 10^6 Btu/hr (293 kW) tests for NO_x contro The various experimental apparatus an test procedures for this fundamental wor are described. Results from entraine flow sulfidation tests and slag sulfu chemistry are fully detailed.

Volume V--Burner Evaluation Dat Appendices. Volume V documents th Quality Assurance program for the LW tests of the DMB evaluation and th Second Generation Low-NO_x burne selection. In addition, computer listings all valid data reported in Volumes I and are included for reference.

Distributed Mixing Burner (DME Evaluation

The objective of this program was demonstrate the performance of the DM on a multi-burner utility boiler. Th involved integrating the DMB conce with Babcock & Wilcox (B&W) burn components to produce a prototyp burner meeting commercial standards. the original program plan, th demonstration was to include a full-sca utility boiler retrofit with DMBs. Th effectiveness of the DMB was to determined by direct comparison with th original equipment burners in or representative operating utility boile

Difficulties in finding a host boiler to participate in a demonstration retrofitting existing burners with the new DMB technology resulted in delays to the overall program. These delays, in turn, caused escalating costs for a utility boiler retrofit with DMBs. Because of these problems, the program was restructured to achieve its objective without installing the DMB in a utility boiler. The approach taken was extensive testing of DMBs at two scales and two B&W commercial burner designs in the EPA Large Watertube Simulator (LWS) coupled with field tests at utility boilers equipped with the two B&W commercial burners. This approach provided data for burner scaleup, performance characteristics of the DMB compared to commercial burners, and commercial burner performance in utility boilers. With this data, the expected performance of DMBs can be extrapolated to utility boilers with some confidence.

LWS Tests

In the original program plan, differences in performance with the DMB were to be determined by direct comparison of the original equipment burners. The elimination of the field installation precluded this comparison and required dependence on research furnace test results. As part of the revised program, the performance of the prototype DMB in the LWS research facility had to be demonstrated to be similar to the performance in a field operating boiler. This objective was achieved by: (1) translating developmental DMB design criteria into practical prototype burners; (2) verifying and optimizing the performance of the prototype B&W DMBs in the LWS; (3) evaluating the performance of two commercial burners in both utility boilers and the LWS; and (4) from that data base, extrapolating the prototype DMB performance to operating utility boilers.

Four different burners were tested:

- 120×10^6 Btu/hr (35 MW) Circular burner
- 60×10^6 Btu/hr (17.6 MW) DRB
- 60×10^6 Btu/hr (17.6 MW)DMB
- 120×10^6 Btu/hr (35 MW) DMB

Two commercial B&W designs, the pre-NSPS Circular burner and the low-NO_x DRB were tested in the LWS to provide a basis on which to judge DMB performance. This comparative evaluation verified safe, efficient operation of the prototype DMB, providing confidence for field application. Limited sorbent injection tests evaluated the effect of burner design on SO_2 reduction potential for both near-burner and upper-furnace locations.

The full-scale 120×10^6 Btu/hr (35 MW) DMB was the key to this demonstration program. The LWS test furnace imposed severe constraints on flame shape and size for a low-NO_x burner. Low-NO_x burners, like the DMB, rely on controlled, delayed mixing of the fuel with air. This delayed mixing generally produces a long flame which may cause operational problems in a boiler. Although equipped with adjustable inner and outer secondary air registers as well as tertiary air ports, the dominant factor In determining ultimate performance (NO_x, flame length) was the coal injector configuration. Iterative modifications were made to the coal Injector to yield the optimum performance for the LWS. There was a direct tradeoff between NO_x emissions and flame length.

The final design selected resulted in unstaged flames about 16 ft (4.9 m) long. At staged conditions (SRB 0.70)*, the flame length increased to about 22 ft (6.7 m]. NO_x emissions for the DMB at these optimum settings at nominal full-load conditions with a burner zone stoichiometry of 0.75 and 20% excess air were 282, 340, 298, and 273** ppm for Utah, Illinois, Comanche, and Wyodak coals, respectively. This performance compares favorably with the two commercial B&W burners tested, as seen in Table 1.

The potential for SO_2 control combined with NO_x reduction was evaluated in a series of sorbent injection trials. Six injection locations were considered. Three sorbents were used: Vicron 45-3 limestone, Colton hydrated lime, and a limited number of tests with a pressure hydrated dolomitic lime. Thermal environment was the key factor determining SO_2 capture efficiency. Upper furnace locations where gas temperatures were about 2200°F (1200°C) yielded the highest captures. Near-burner injection, either with the coal or through tertiary air ports, generally gave the poorest SO_2 capture. The pressure hydrated dolomitic lime was the most effective of the three sorbents on a Ca/S molar ratio basis; however, the advantage disappears when considered on a mass addition basis because of the additional magnesium component.

*SR_B Burner zone stoichiometry, fraction of theoretical air

**All emission concentrations reported are corrected to 0 percent O_2 on a dry basis, except where indicated.

Field Tests

Field testing was conducted at two boilers, one equipped with the Circular burner and one with the DRB. The boilers were selected by B&W to be comparable in terms of age, capacity, coal characteristics, and firing configuration. The Circular burner was evaluated at the Colorado Public Service Comanche Generating Station, Unit 2 located in Pueblo, Colorado. The DRB was tested at the Wyodak Generating Station, Gillette, Wyoming, owned by Pacific Power and Light Company and the Black Hills Power and Light Company. Testing was conducted for 1 week at Comanche in December 1984 and for 2 weeks at Wyodak in February 1985. Both the Comanche and Wyodak units have a nominal maximum capacity (MCR) of 350 MW_e (gross).

Both boilers fire subbituminous coal and use a front and rear wall firing configuration. The front and rear wall burners at the Comanche boiler are directly opposed with four rows of four burners each. The front and rear burners at Wyodak are offset to avoid flame interactions and are arranged in five rows of three burners each. The boilers have comparable furnace cross-sectional dimensions, but the Wyodak boiler has a taller furnace to accommodate the five burner rows. Thus, the Wyodak furnace has a lower ratio of firing rate to cooled surface area.

During testing, the boilers were generally operated in a normal fashion by the operators. Thus, the burner settings, load, and excess air were controlled by plant personnel. The overfire NO_x ports were closed during the day at the Comanche boiler, and returned to their normal open position of 18% at night. Both the Circular boiler and the DRB operated satisfactorily during the tests. Exact flame lengths could not be determined with the available observation ports. Both burners showed a high combustion efficiency, and large imbalances of fuel or air distribution were not observed.

Both boilers operated over a narrow excess O_2 range, 2.5 to 3.5% at Comanche and 3.8 to 4.0% at Wyodak. Thus, the data were not sufficient to establish NO_x emissions with excess O_2. Figure 1 shows NO_x emissions at the two boilers as a function of load. Both correlations show a similar slope, with lower NO_2 emissions for the DRB at Wyodak. Nominal NO_x emissions with the

Table 1. *Comparison of Burner Performance in the LWS Firing Utah Coal ($SR_T = 1.20$)*

	DMB		DRB	Circular
	Full-Scale	Half-Scale	Half-Scale	Full-Scale
Firing Rate (10^6 Btu/hr) (MW)	120 (35.2)	60 (17.6)	60 (17.6)	120 (35.2)
SR_B	0.70	0.70	1.20	1.20
Furnace Exit Gas Temperature (°F) (°C)	1792 (978)	1776 (969)	1776 (969)	1828 (998)
NO_x (ppm @ 0% O_2)	282	350	390	380
Flame Length (ft) (m)	22 (6.7)	18 (5.5)	18 (5.5)	>22 (6.7)

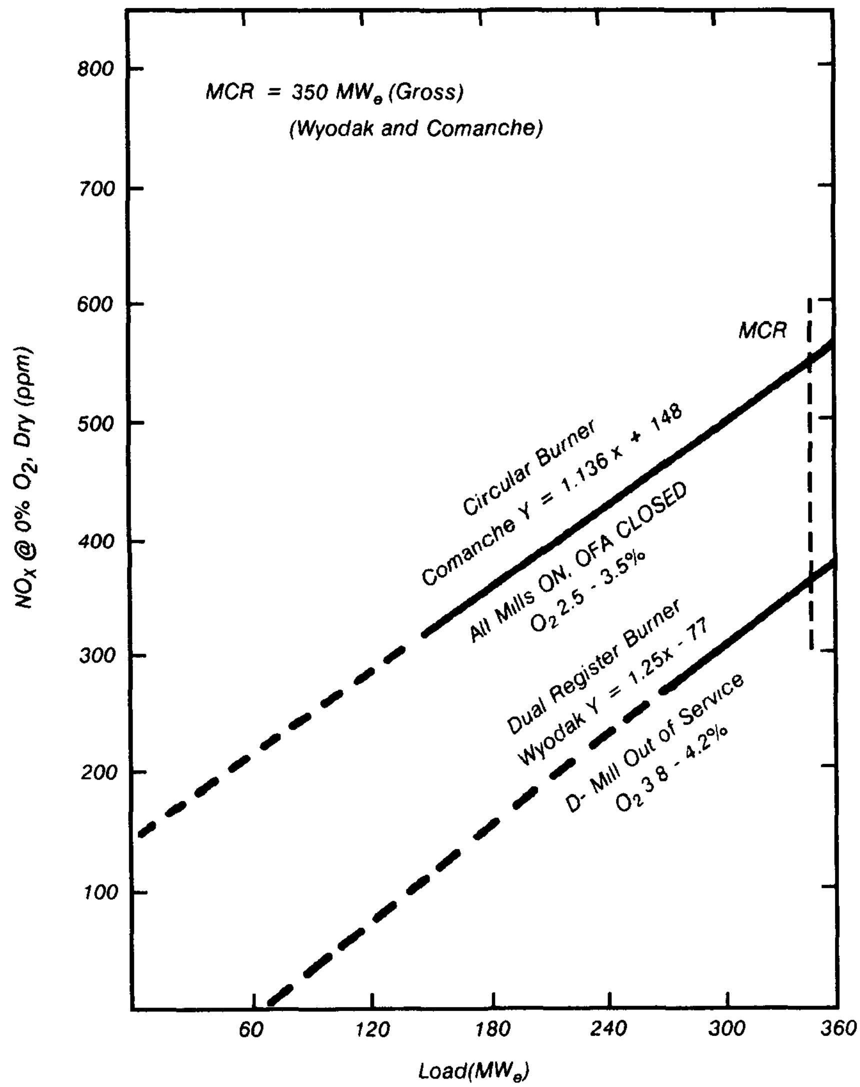

Figure 1. NO_x emissions vs. boiler load.

Circular burner at Comanche were 550 ppm at 0% O_2[0.64 lb/106 Btu (0.29 kg/kJ)]. Full load emissions at Wyodak with all mills in service were 395 ppm at 0% O_2[0.46 lb/106 Btu (0.21 kg/kJ)].

Second Generation Low-NO_x Burner Evaluation

The initiation of the LIMB (Limestone Injection Multistage Burner) technology demonstration at the Ohio Edison Edgewater Station, Unit 4, provided an opportunity to broaden the relevance of this project. The objective of this LIMB program with respect to burner design was to provide a commercial pulverized-coal burner that demonstrates a reduction in nitrogen oxide (NO_x) emissions of at least 50% relative to uncontrolled performance of the original Babcock & Wilcox (B&W) Circular burners.

The three B&W low-NO_x burner designs being considered--the DRB, Babcock-Hitachi NO_x Reducing (HNR) burner, and the XCL burner--were tested at full scale in the EPA Large Watertube Simulator (LWS) to determine the optimum design for use at the Edgewater boiler as part of this study. Burners sized at 78 x 10^6 Btu/hr (22.9 MW), the same size as the Edgewater burners, were tested in the LWS, minimizing scaleup questions. By coincidence, the LWS has a firing depth of 22 ft (6.7 m), essentially the same as Edgewater Unit 4. Screening tests of the three basic burner designs were conducted firing Pittsburgh No. 8 coal, the coal to be used during the LIMB demonstration, to determine optimum operating conditions. In addition to available burner adjustments, a number of burner hardware components were also evaluated to establish the optimum burner design. Sorbent injection tests were completed for a selected configuration of each basic burner to determine the effect of burner design on SO_2 capture. Following the screening tests of the three burners, selected XCL burner configurations were characterized with three additional, distinctly different coals to broaden the application of this new burner.

Optimization tests of the three basic burner designs screened the available burner adjustments as well as the various burner component configurations. The three basic components of each burner (the coal injector, inner secondary air zone, and outer secondary air zone) were evaluated in these screening tests. The results from these tests can be easily eneralized for all three low-NO_x burners .vith respect to sensitivity of performance. In each case, the coal injector was the dominant factor that determined the key performance characteristics of NO_x, flame length, and carbon burnout. Both the design of the coal injector and the available adjustments could produce up to 67% reduction in NO_x emissions. The outer secondary air zone, the degree of swirl, and the air flow rate through the outer passage were second in importance to burner performance. The inner air zone parameters of swirl and air flow rate generally had the least effect on performance.

Consistent and recurring throughout the screening tests of all three burners was the close correlation of NO_x emissions with flame length. Data from tests of the DRB, HNR burners, and the initial screening tests of the XCL burner, summarized in Figure 2, clearly shows this correlation. At 20% excess and full load conditions, these data indicate that, for a flame less than the firing depth of the Edgewater boiler, NO_x emissions in the range of about 300-400 ppm were achieved by several burner configurations. With flame length as the most severe constraint at the Edgewater boiler, only 8 of the 20 burner configurations tested in this program and 5 Phase V DRB configurations achieved flames less than 22ft (6.7 m) long. These are listed in Table 2.

From the numerous burner configurations tested, two stand out as suitable for application for the LIMB demonstration. All configurations tested met the requirements of a firing capacity of 78 x 10^6 Btu/hr (22.9 MW) burner, a throat diameter no greater than 35 in. (88.9 mm), and mechanical reliability meeting commercial standards. The Edgewater boiler also imposed the constraint on flame length, 22 ft (6.7 m), and on maximum tolerable burner pressure drop, about 5 in. (127 mm) water gauge. In addition, the burners had to produce a stable flame with low emissions but high combustion efficiency. The two configurations meeting all those conditions were:

- XCL burner with 30° impeller in the standard coal nozzle with appropriate outer vane design.
- XCL burner with 20° impeller in an expanded coal nozzle.

In addition to meeting all Edgewater boiler requirements, the two impeller-equipped XCL burner configurations offer a very effective way to optimize performance to suit the application, using the adjustable coal impeller. For both designs, flame length and NO_x emissions can be varied simply by moving the impeller a matter of inches. The impeller adjustment can thus be used to tune the burner for maximum NO_x reduction within the constraints of available firing depth.

Alternate Concepts for SO_x, NO_x, and Particulate Emissions Control from a Fuel-Rich Precombustor

The potential for simultaneous control of ash, NO_x, and SO_x emissions from coal-fired boilers and heaters by combustion external to the furnace has made precombustor development an area of great interest and effort. A precombustor burns coal in a chamber outside the normal furnace region. An example of a simple precombustor is shown in Figure 3.

Aerodynamic separation and slag drainage remove most of the coal mineral matter before entry into the furnace. Also, staged combustion and fuel reburning have been shown to be an effective way to control NO_x emissions. It has been proposed that the use of calcitic sorbent or possibly other additives in a fuel-rich precombustor can produce significant reductions in overall SO_2 emissions. Successful control of all three pollutants would allow coal users to circumvent expensive exhaust stream cleanup equipment and help avoid derating in oil or gas retrofit applications.

The issue of sulfur capture under fuel-rich conditions has been an area of uncertainty and much recent interest. The fuel-rich reactions of:

$$H_2S + CaO \rightarrow CaS + H_2O \text{ and}$$
$$COS + CaO + CaS + CO_2$$

are theoretically more effective at capturing gas-phase sulfur than the well studied fuel-lean reaction:

$$SO_2 + CaO + 1/2\ O_2 \rightarrow CaSO_4,$$

from both a thermodynamic and kinetic standpoint. However, at the time this program was initiated, the operating conditions which promote these fuel-rich reactions had not been fully investigated. In addition, the presence of a liquid slag in the reactor was thought to be a potential source of sulfur capture or regeneration which required additional research.

The program involved two phases: (I) exploratory testing of a pilot-scale coal precombustor [293 kW (1x10^6 Btu/ hr)] to help identify critical operating parameters for precombustor systems with NO_x control and the potential for sulfur control; and (2) a more fundamental investigation of factors affecting sulfur removal under fuel-rich conditions.

The pilot-scale testing indicated that there was significant sulfur captured as calcium sulfide (CaS) by suspended sorbent particles in the fuel-rich combustion zone of the precombustor. However, there was evidence that sulfur was released from the CaS when exposed to a fuel-lean flame front. There was also concern that sulfur in the slag layer was evolving back into the gas phase. A combination of high solids carryover, complexities of sampling in the pilot-scale precombustor, and a growing number of fundamental questions concerning fuel-rich sulfur capture led to Phase 2, which is the main topic of the alternate concepts report.

The objective of Phase 2 was to make a detailed investigation of several key elements in the fuel-rich sulfur capture process, including: 1) the formation of stable sulfides in the entrained flow region of a precombustor using calcium-based sorbents, 2) the evolution of sulfur from coal in an entrained flow process, and 3) the stability of sulfur in molten slag layers.

This program focused on the area of fuel-rich sulfur capture, since little more than theoretical predictions and a few uncertain tests results were available. Several obstacles face the successful use of calcitic sorbents in fuel-rich coal-fired precombustors. The most important issues were investigated in this program, including: extent of entrained flow sulfidation, the speciation of sulfur as it evolves from coal under fuel-rich conditions, the equilibrium solubility of sulfur in molten slags, the impact of fluxing additives on slag fluidity and sulfur solubility, and the rate at which sulfur regenerates from slags containing a super-equilibrium level of sulfur.

The major conclusions from this program are:

- The sulfidation reactions betweer CaO and H_2S or COS are fast and under optimum conditions,car capture most of the gas-phase sulfu in a fuel-rich precombustor.
- The conditions which favor fuel-rict sulfur capture (deep sub stoichiometric operation and mod erate temperatures) can result ii poor carbon burnout and low sla(fluidity.
- Typical molten coal ash and mixture: of coal ash and CaO are incapable c holding large amounts of sulfur in coal precombustor environmen when at equilibrium.

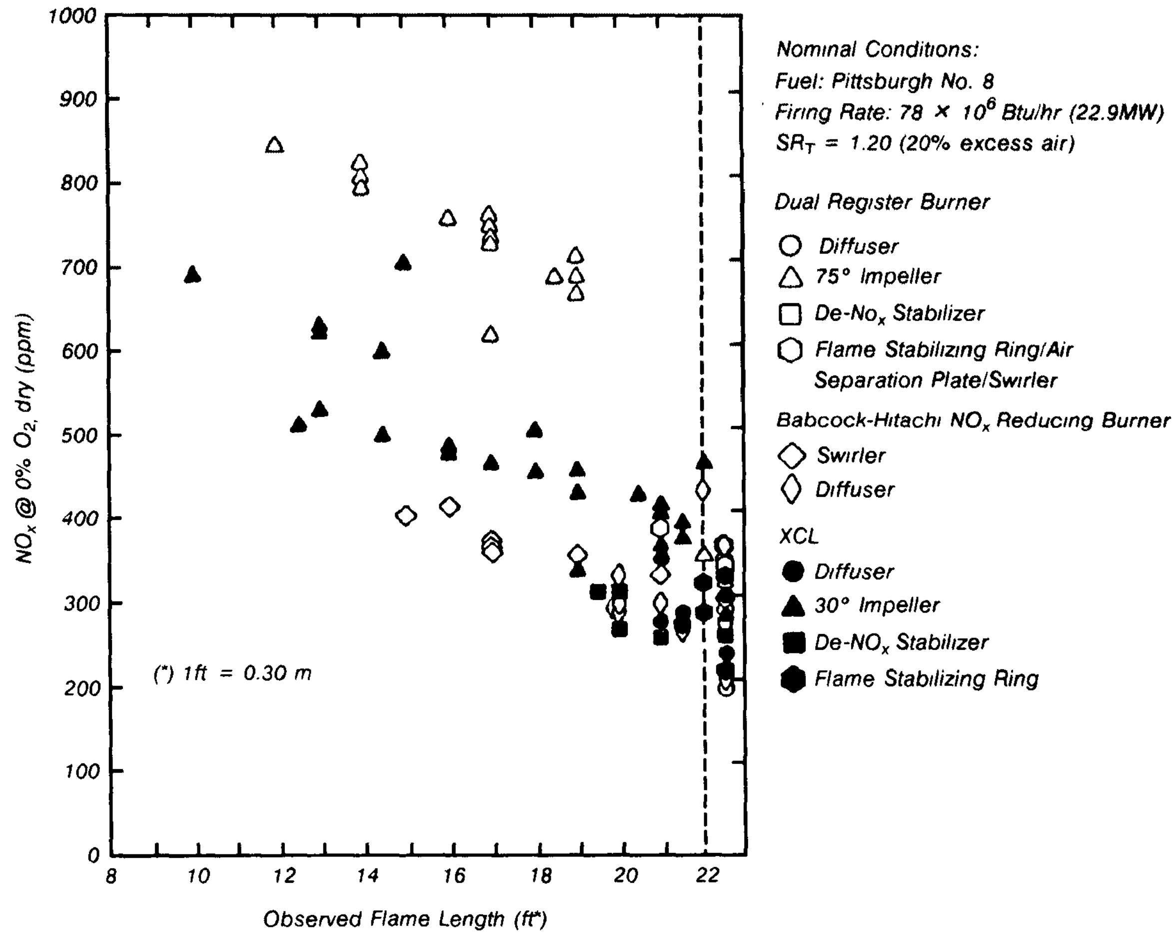

Figure 2. *Correlation of NO_x emissions with flame length.*

- Coal ash/CaO slags quickly desulfurize from super-equilibrium levels of sulfur at typical precombustor temperatures and gas compositions, indicating that rapid slag drainage designs are required.
- Slag fluxing additives, such as B_2O_3, can extend operating conditions which will make fuel-rich sulfur removal a possibility over a wider range of coal types and precombustor systems.

Table 2. Second Generation Low NO_x Burners with Flames <22 ft (6.7m) Long [78× 10^6 Btu/hr (22.9 MW), SR_T =-1.20]

Burner	Configuration	NO_x @ 0% O_2, ppm	Flame Length, ft (m)	Fly Ash Carbon, wt%	Burner ΔP, in. W.G. (mm W.G.)
Low-Velocity DRB	75° Impeller	708	18 (5.5)	7.28	6.0(152)
Phase V DRB	Diffuser	372	20-21(6.1-6.4)	6.12	10.8(274)
	Venturi	350	20-21(6.1-6.4)	6.45	11.0(279)
	Diffuser, ASP	326	22(6.7)	3.20	6.4(162)
	Diffuser, FSR	292	22(6.7)	6.96	10.5(267)
	Diffuser, FSR, ASP	328	22(6.7)	5.16	11.0(279)
HNR	Swirler	348	18-20(5.5-6.1)	N/A	7.20(183)
	Diffuser	289	20(6.1)	3.34	7.50(190)
XCL	DNS	288	20(6.1)	N/A	8.20(208)
	30° Impeller, Standard Nozzle	374	20-22(6.1-6.7)	4.42	3.30(84)
	30° Impeller, Expanded Nozzle	546	19-20(5.8-6.1)	1.36	4.30(109)
	20° Impeller, Expanded Nozzle	338	21(6.4)	4.92*	4.90(124)
	30° Impeller, Standard Nozzle, Fixed Outer Vanes	420	21-22(6.4-6.7)	3.40	4.60(117)

*Data for SR_T = 1.16

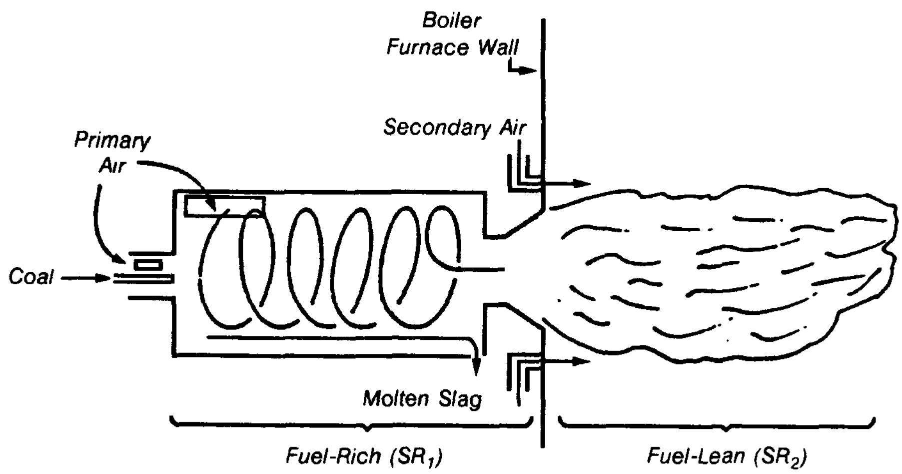

Figure 3. Common cyclonic precombustor in staged combustion configuration attached to boiler furnace wall.

A. Abele, J. LaFond, J. Cole, G. Kindt, W. Li, E. Moller, R. Payne, and J. Reese are with Energy and Environmental Research Corp., Irvine, CA 92718.
***P. Jeff Chappell** is the EPA Project Officer (see below).*
The complete five volumes, entitled "Field Evaluation of Low-Emission Coal Burner Technology on Utility Boilers:"
"Volume I. Distributed Mixing Burner Evaluation," (Order No. PB90-155 680/AS; Cost: $23.00)
"Volume II. Second Generation Low-NO_x Burners;" (Order No. PB90-155 698/AS; Cost: $23.00)
"Volume III. Field Evaluations;" (Order No. PB90-155 706/AS; Cost: $23.00)
"Volume IV. Alternate Concepts for SO_x, NO_x, and Particulate Emissions Control from a Fuel-Rich Precombustor;" (Order No. PB90-155 714/AS; Cost: $23.00)
Volume V. Burner Evaluation Data Appendices," (Order No. PB90-155 722/AS Cost: 23.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Official Business
Penalty for Private Use $300

EPA/600/S7-89/015