United States
Environmental Protection
Agency

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

Research and Development

EPA/600/S7-88/019 Jan. 1989

Project Summary

Evaluation of Low-Emission Coal Burner Technology on Industrial Boilers

B. A. Folson, A. R. Abele, J. L. Reese, and T. M. Sommer

The Distributed Mixing Burner (DMB) is a low-NO_X pulverized-coal burner for wall-fired boiler applications. The burner operates under reducing conditions in the primary flame zone to minimize NO_X emissions while an overall oxidizing environment is maintained in the furnace to minimize slagging and corrosion. This operation is accomplished by using air ports around the burner throat to provide staged combustion conditions at each individual burner.

This report gives results of a field evaluation of the DMB on a 98 kg/hr (215,000 lb/hr) steaming capacity, four-burner, front-wall-fired boiler. Prior to the DMB retrofit, field tests established baseline operating conditions with the pre-NSPS (New Source Performance Standards) burners originally installed in the boiler. Following DMB installation, the boiler was operated and tested with the new burners for 17 months. Under routine operation, the DMBs reduced NO_X emissions by about 50%–from a baseline condition of about 0.96 to about 0.46 lb/10^6 Btu (418 to 200 ng/J). Under carefully controlled, optimized conditions, NO_X emissions were further reduced another 20%–to about 0.3 lb/10^6 Btu (131 ng/J).

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 a separate report of the same title (see Project Report ordering information at back).

Introduction

Staged combustion is one of the most effective techniques for reducing NO_X emissions from fuels containing high levels of nitrogen. Its objectives are to: (1) reduce the peak flame temperature which significantly reduces the oxidation of nitrogen introduced by the combustion air,and (2) produce an oxygen-deficient (fuel-rich) flame zone that inhibits oxidation of all nitrogen species present, including those introduced by the fuel itself. The concept involves firing the fuel under oxygen conditions (primary flame zone) initially followed by secondary air addition to complete the combustion process in an air-rich environment (secondary flame zone). In the fuel-rich primary zone, nitrogen compounds are reduced to N_2 preferentially prior to adding the secondary air. The effectiveness of this staged air addition in reducing NO_X emissions depends on combustion conditions, particularly in the fuel-rich primary zone. The optimum primary zone stoichiometry is typically in the range of 70% theoretical air (TA). Staged combustion has been demonstrated to be effective in reducing NO_X emission on full-scale wall-fired boilers through the use of overfire air ports. However the primary zone stoichiometry must be maintained approximately at stoichiometric conditions (100% TA) to avoid slagging and corrosion in the lower furnace and to achieve adequate char burnout. This limits the effectiveness of NO_x control.

For the last several years, the EPA has been developing a low-NO_x pulverized-coal burner that achieves staging by means of air ports around a circular burner. This Distributed Mixing Burner (DMB) allows a fuel-rich primary zone to be established in the furnace adjacent to the burner while maintaining an overall oxidizing environment farther into the furnace to minimize slagging, corrosion, and char burnout.

Figure 1 shows how the fuel/air mixing is staged sequentially. The combustion process occurs in three zones. In the first zone, pulverized coal transported by the primary air combines with the inner secondary air to form a very fuel-rich (30 to 50% TA) recirculation zone which provides flame stability. The coal devolatilizes, and fuel nitrogen compounds are released to the gas phase. Outer secondary air is added in the "burner zone" where the stoichiometry increases up to about 70% TA. Air to complete the combustion process is supplied through tertiary air ports outside the burner throat. This allows substantial residence time in the burner zone for decay of bound nitrogen compounds to N_2 and radiative heat transfer to reduce peak temperatures. The tertiary air ports surrounding the burner throat provide an overall oxidizing atmosphere and minimize interactions between adjacent burners.

The objective of this program was to integrate the DMB concept with commercial burner components and to field test the DMB performance on a full scale boiler. The goal was to attain NO_x emissions less than 87 ng/J (0.2 lb/10^6 Btu) or as low as possible without adverse effects on boiler operability and durability, thermal efficiency, and the emission of other pollutants.

The characteristics of industrial and small utility boilers in the U.S. were analyzed, and several Foster Wheeler boilers were identified as candidate host units. Western Illinois Power Cooperative's (WIPCO's) Pearl Station 1 was selected as the host boiler. This unit is a 98 kg/hr (215 x 10^3 lb/hr) steam front-wall-fired utility boiler with four pre-NSPS Foster Wheeler Intervane Burners. A field test was conducted to establish the baseline performance.

A prototype DMB was designed by integrating the DMB design criteria with Foster Wheeler burner components. Some compromises were necessary to meet the space and geometrical requirements imposed by the host boiler.

Comprehensive burner tests were conducted in two research furnaces with an Intervane Burner (to establish baseline performance) and with several configurations of the prototype DMB. The tests of the initial prototype DMB achieved low NO_x emissions but the flame stability was unacceptable at the burner operating point, probably due to the differences in design between the research and commercial burner components. To improve flame stability, the prototype burner exit was modified to incorporate Foster Wheeler's proprietary Controlled Flow Burner exit geometry. The Controlled Flow Burner is Foster Wheeler's first generation low-NO_x design which was offered commercially until 1979. It has since been replaced by a second generation design. Subsequent tests demonstrated that this DMB configuration met all operational requirements necessary for the field installation. Consequently, the field-operable DMBs were based on this design. Subsequently, other prototype DMB configurations which did not include proprietary burner design parameters were tested and optimized. These DMB configurations achieved low NO_x emission and adequate flame stability.

The host boiler was retrofitted with DMBs in the spring and summer of 1981 and the burner/boiler performance was evaluated for 17 months.

Host Boiler

Figure 2 shows the general arrangement of the host boiler, WIPCO's Pearl Station Unit 1. Table 1 lists the design and operating characteristics. This unit is representative of a large number of medium-pressure pre-NSPS industrial and small utility boilers. There is no reheater or economizer, and a portion of the steam is generated in the convective pass. This unit was erected in 1965 by Foster Wheeler and was equipped with four Intervane Burners in a 2 x 2 array. The Intervane Burner is Foster Wheeler's standard commercial pre-NSPS burner. Pearl Station is the principal power plant of WIPCO and normally operates base-loaded.

Pearl Station fires a variety of fuels. Small quantities of coal are purchased from several mines based on cost ($/$10^6$ Btu) primarily. Since the beginning of this program, coals from four mines in Indiana, Illinois, and Missouri have been fired. All are high volatile bituminous coals but their compositions vary over a considerable range.

To establish the DMB operatin requirements and to determine th baseline performance with the origin burners, a comprehensive field test wa conducted. In general, the measure baseline performance was typical many pre-NSPS units. Carbo utilization, as measured by carbo content of the particulate emissions usin coal ash as a tracer was typicall 99.65% CO emission was less than 4 ppm, and hydrocarbon and ammon emissions were negligible. NO emissions ranged from 807 to 847 ppm which corresponds to 395 to 412 ng/ (0.91 to 0 95 lb/10^6 Btu) Since this boile was constructed before 1971, it is no subject to the NSPS emissio regulations.

DMB Design

Figure 3 shows the design of th central portion of the prototype DM which integrates the DMB design criteri with Foster Wheeler commercial burne components and meets the host boile requirements. This burner design meet all of the DMB design criteria except fo the burner exit. The windbox depth an burner-to-burner spacing of the hos boiler, which are typical of domesti boiler designs, required a short burne exit The exit geometry configuratio illustrated is the initial configuratio tested in the research furnace. Th burners installed at Pearl Station ar similar except for the exit geometr which was modified to match Foste Wheeler's proprietary Controlled Flow Burner parameters.

DMB Installation

The primary difference in th installation requirements for the DMB an conventional burners is the tertiary ai port array required for the DMB. Base on the research furnace tests, tertiary ai ports should be arranged to distribute th air uniformly around each burner i discrete jets. This requires tertiary ai ports between the burners and outboar of the burner array The preferred DMB application is in new boilers wher adequate provision for the tertiary ai ports can be provided as part of th boiler design. Since the DMB installatio in the host boiler was a retrofit, som compromises in both the DMB desig and the host boiler equipment wer required.

After considerable analysis an discussion, the compromise por arrangement illustrated in Figure 4 wa selected. Thirteen tertiary air ports we installed. four above the burners, fou

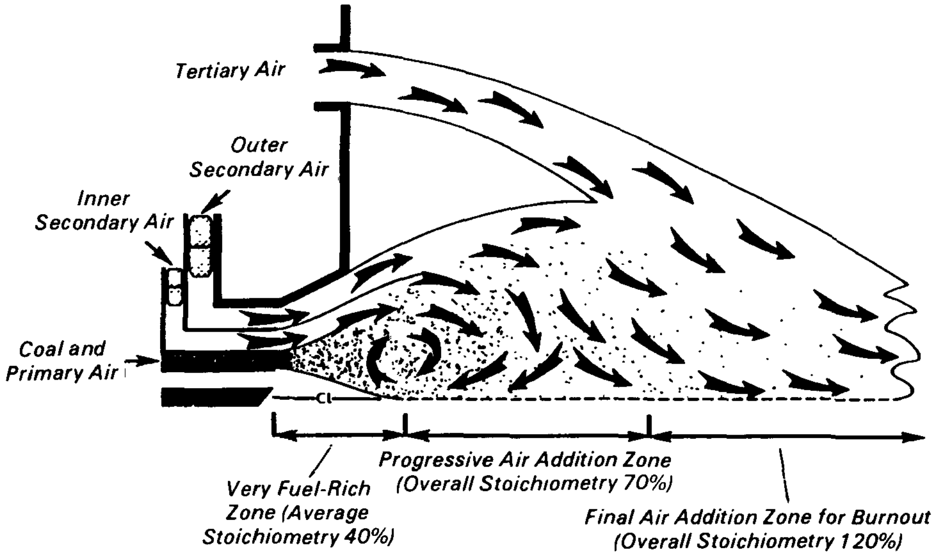


Figure 1. *Distributed mixing burner concept.*

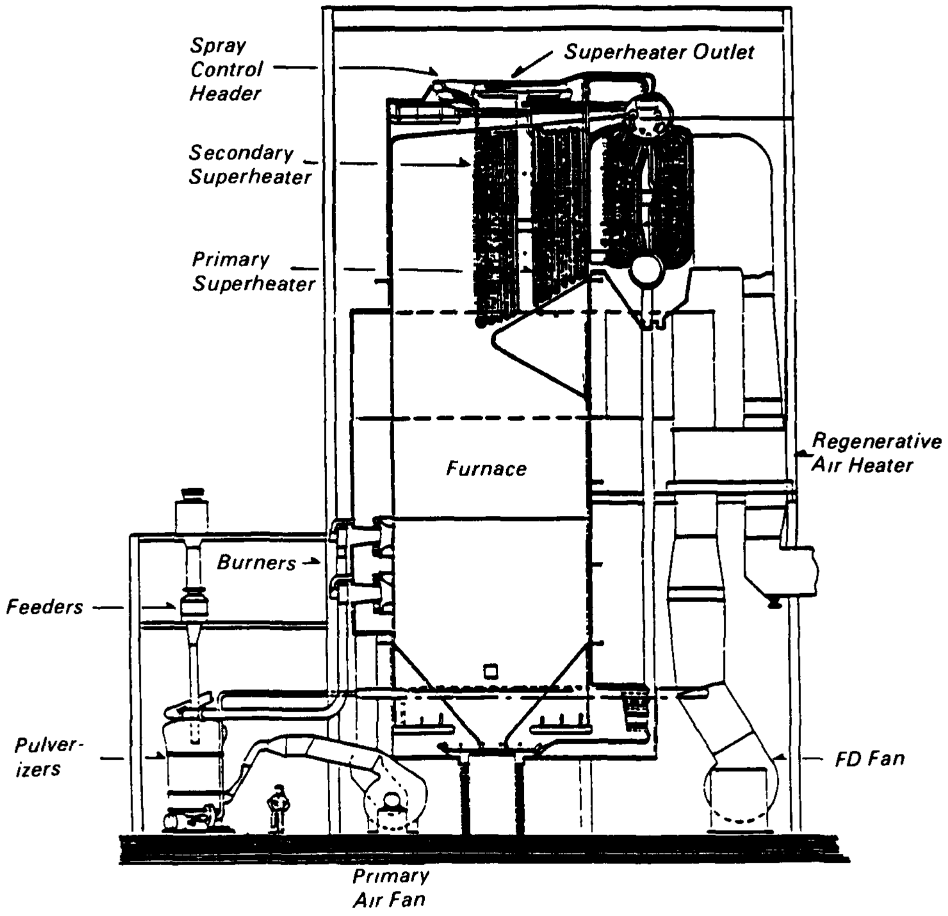


Figure 2. *WIPCO's Pearl Station Unit 1.*

below the burners, four outboard of the burners, and one in the center of the burner array. This arrangement distributes the tertiary air around and between the burners while minimizing structural problems. The ports above the burner are the maximum size that will clear the buck stay. The port in the center was reduced in diameter to allow clearance for its control mechanism between the burner registers. The ports along the sides have been moved to allow free flow into the pulverizer ducts. The bottom of the windbox has been lowered to provide a plenum for installation of the lower ports.

The modifications to the host boiler equipment included:

- *Front Wall Replacement* - Due to the large number of complex tube bends, the entire front wall had to be replaced.
- *Buck Stay Removal* - The buck stay between the burners had to be removed, and additional windbox structures were constructed to handle the pressure loads.
- *External Hopper Support* - The front wall strength was inadequate to support the hopper due to the large number of tube bends. An external hopper support was constructed to handle the hopper weight.

Since one pulverizer would be taken out of service at low loads, the burners were designed to operate with the tertiary ports both closed and open. Electrical drives were provided to control all tertiary air ports and registers, a total of 18 drives. With the ports closed, leakage airflow (for cooling) resulted in an average burner zone stoichiometry of about 100% TA. Opening the ports fully and restricting the airflow through the burner throats using the sleeves and registers reduced the burner zone stoichiometry to near the DMB design point, 70% TA.

Field Test Results

Since the completion of the DMB retrofit, the host boiler has operated in commercial service for 45 months (except for brief outages). This includes 17 months of intensive testing with the tertiary air ports open as part of this program and 28 months of normal operation by the WIPCO operators with closed or open tertiary air ports.

The test program included short-term tests over a range of burner settings and operating conditions to establish optimum settings and extended periods of continuous monitoring while the unit

Table 1. Initial Demonstration Site Characteristics

Parameter	Value
Boiler	
Configuration	Single-Wall-Fired
Capacity MCR	98 x 10^3 kg/hr (215 x 10^3 lb/hr)
Peak	111 x 10^3 kg/hr (245 x 10^3 lb/hr)
Burners	
Type	Foster Wheeler Intervane
Array	2 x 2
Capacity MCR	20 Thermal MW (69 x 10^6 Btu/hr)
Throat Diameter	61 cm (24 in.)
Spacing Horizontal	182 cm (71.5 in.)
Vertical	198 cm (78.0 in.)
Furnace	
Construction	Membrane Wall
Depth	6.28 m (20.6 ft)
Width	5.01 m (16.4 ft)
Burner Zone Liberation Rate	492 Thermal kW/m^2
(BZLR)	156 x 10^3 Btu/hr-ft^2)
Fuel	
Coal Type	Indiana Bituminous
Pulverizers Type	Foster Wheeler MB
Number	2
Air Supply	
Air Heater Type	Regenerative
Secondary Air Temperature	265°C (510°F)
Draft	Pressurized
Windbox Depth	132 cm (52 in.)
Burner Pressure Drop (nominal)	8.9 cm H_2O (3.5 in H_2O)

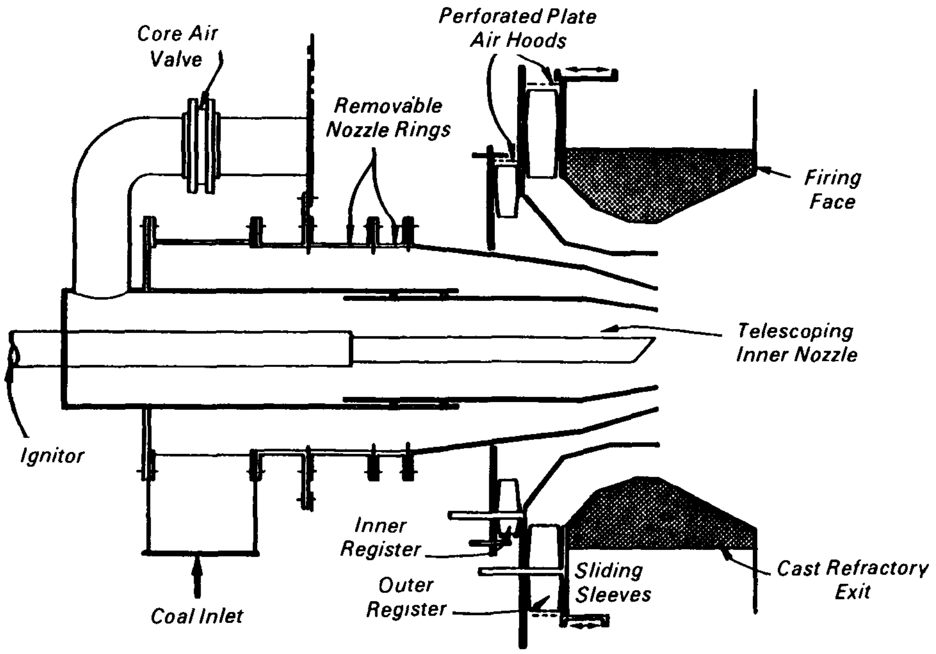


Figure 3. *Initial prototype DMB based on Foster Wheeler components (tertiary ports not shown).*

was operating by WIPCO following load Measurements included boiler contro room data, burner settings, emissions boiler efficiency, and corrosion.

The large number of burner controls on the DMBs allowed the burner to be adjusted to provide wide ranges of flow conditions, flame patterns, and hence emissions and boiler efficiency. Minimum NO_x emissions were produced by adjusting the burners to achieve: (1) short flame standoff distance, (2) low burner zone stoichiometry near the DMB design point (70% TA), and (3) balanced air and coal flows to the four burners.

Figure 5 shows data from several tests over a range of burner zone stoichiometries at two excess air levels. NO_x emissions were slightly higher for the higher excess air level, but this effect was small compared to the impact of burner zone stoichiometry. NO_x emissions were minimized at low burner zone stoichiometries as expected from the research furnace tests.

Under controlled conditions, NO_x emissions as low as 259 ppm @ 0% O_2 or 129 ng/J (0.29 lb/10^6 Btu) were achieved at full load. This is a reduction of 69% from the NO_x emissions measured during the 30-day baseline test with the pre-NSPS Intervane Burners. A wide range of burner settings, was used. Burner zone stoichiometry was in the range of 72 to 77% TA, and excess O_2 was in the range of 2.87 to 3.94%. These low NO_x operating conditions were obtained over a 9-month period and represent the best operating conditions achieved on each specific day.

Maintaining low-NO_x emissions for extended periods proved difficult for the operators due to burner balance problems. Based on all available data, the burner balancing problems were probably due to non-uniform entrainment of tertiary air into some of the flames. It is expected that the operation of the burners with the registers almost fully closed and the specific tertiary air port array interact to result in non-uniform entrainment of tertiary air into the four flames. Figure 6 illustrates the three positions of tertiary air mixing patterns.

Due to these burner balancing problems, the extended tests were conducted with more conservative burner settings which resulted in higher NO_x emissions. Four extended tests were conducted including two 30-day tests. Table 2 compares the emissions measured during 30-day tests with the baseline pre-NSPS burners and the

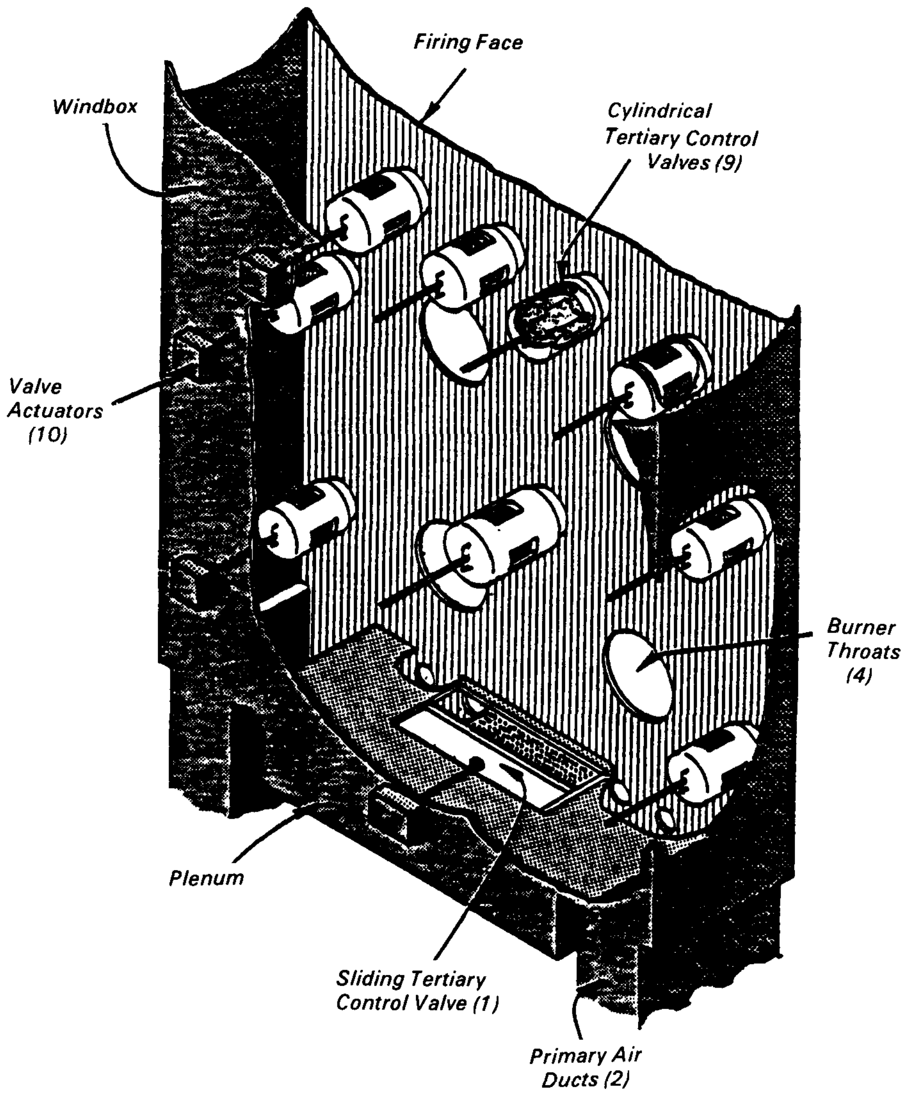


Figure 4. *Tertiary air ports for WIPCO DMBs.*

DMBs. The DMBs reduced NO_x emissions by 49%. CO emissions and the carbon content of the fly ash were higher for the DMB. The hydrocarbon emissions were negligible for both tests. SO_2, SO_3, CO_2, and total particulate emissions are sensitive to fuel composition, and the differences in the table should not be attributed to burner performance. The particulate carryover, expressed as the particulate-to-coal ash mass ratio, was similar for the two tests.

Boiler performance data obtained during the 30-day test are presented in Table 3. Based on these and other data, the DMBs had no discernible impact on air heater outlet temperature and final eam temperature. The only efficiency losses which can be impacted by the burners are the dry gas and combustible losses. The dry gas loss in Table 3 is slightly higher for the DMB since the boiler was operated at higher excess O_2 during the test. Note that the DMBs could be set up to operate at lower excess O_2, and this would result in dry gas losses comparable to the pre-NSPS burners. Combustible loss was higher for the DMBs, and this accounts for most of the reduction in boiler efficiency.

To assess the impacts of the DMBs on tube wall metal wastage, comprehensive measurements were made, including, installation/removal/-analysis of four corrosion panels in the furnace and field measurements of tube wall thickness using ultrasonic techniques over a 47 month period (12 months with the pre-NSPS burners and 35 months with the DMBs). The results of these tests showed that the DMBs had no discernible impact on tube wall metal wastage.

Summary and Conclusions

A field evaluation of the DMB has been completed on a 98 kg/hr (215 x 10^3 lb/hr) front-wall-fired boiler. This DMB installation was necessarily a retrofit application. To meet the requirements of the host boiler, some compromises in the DMB design were required, especially the tertiary air ports. In addition to burner replacement, it was necessary to replace the front wall, modify the windbox, replace the burner management system, and provide an alternate support structure for the hopper. However, the preferred DMB application is in new boilers where it should be possible to adjust the windbow and furnace wall designs to avoid many of these problems.

The field tests demonstrated that, in comparison to the original equipment pre-NSPS burners, the DMBs reduced NO_x emissions by about 50% under routine operation and up to 70% under carefully controlled conditions. There was no impact on steam temperature, air heater discharge temperature, boiler capacity, or furnace tube wall metal wastage. Boiler efficiency was lower with the DMBs due principally to increased carbon loss. This loss was offset partially by reductions in fan power due to the low windbox-to-furnace pressure differential required by the DMBs.

Overall, the host boiler operators have been pleased with the DMBs and have elected to leave the DMBs in operation rather than restoring the original burners. At present, the host boiler remains in commercial service with the DMBs operating with the tertiary air ports open but not at low burner zone stoichiometry. Under this condition, carbon loss is in the same range as with the original burners.

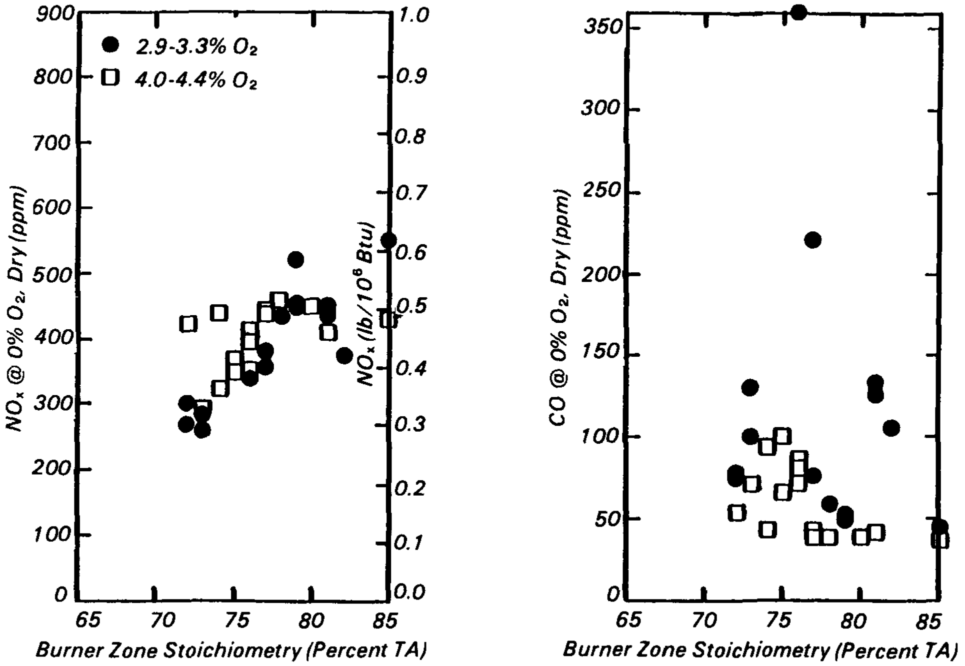
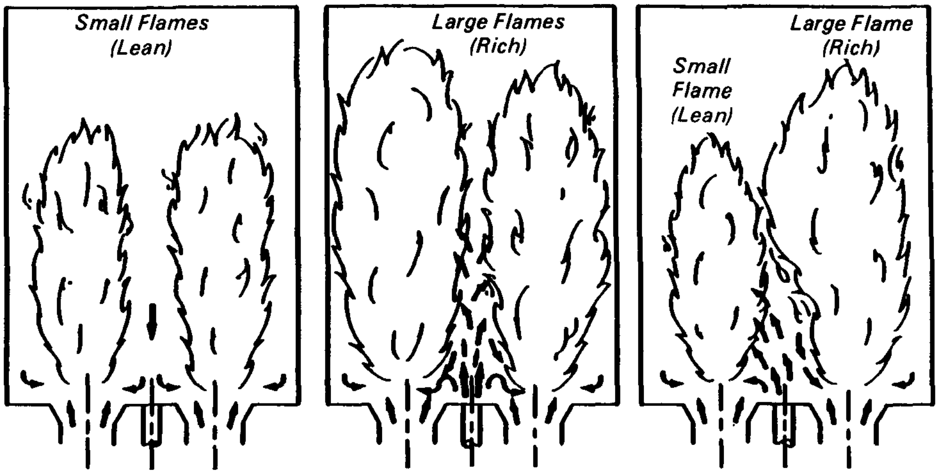


Figure 5. Effect of burner zone stoichiometry on emissions for the DMBs in the host boiler.



A. Unstaged with balanced flames

B. Staged with balanced flames

C. Staged with imbalanced flames

Figure 6. Tertiary air mixing patterns.

Table 2. Emissions Measured During 30-Day Tests of the Host Boiler

	Baseline Pre-NSPS Burners	DMB
Averages Over 30-Day Period		
Load	18.5	16.6
O_2 (%)	3.6	4.0
NO_x @ 0% O_2 (ppm)	847	432
CO @ 0% O_2 (ppm)	37	85
SO_2 @ 0% O_2 (ppm)	3299	3682
CO_2 @ 0% O_2 (%)	18.5	18.3
Short Term Measurements		
SO_3 @ 0% O_2 (ppm)	25	47
HC as C_3 @ 0% O_2 (ppm)	< 1	< 1
Total Particulate @ 0% O_2 (gr/scf)	5.93	5.95
Particulate/Coal Ash (mass ratio)	0.828	0.734
Carbon in Fly Ash (%)	3.85	6.62

Table 3. Boiler Performance Measured During 30-Day Tests of the Host Boiler

	Baseline Pre-NSPS Burners	DMB
Operating Conditions		
Steam Flow	81,633 kg/hr 180,000 lb/hr	81,905 kg/hr 180,600 lb/hr
Steam Temp	473°C 884°F	466°C 870°F
Excess Air (%)	25.4	26.5
Air Heater Gas Outlet Temp, Undiluted	186°C 367°F	207°C 404°F
Coal Calorific Value	5347 kcal/kg 9622 Btu/lb	5,709 kcal/kg 10,274 Btu/lb
Efficiency Losses (%)		
Dry Gas	6.308	6.478
H_2O from Fuel	5.605	5.419
H_2O in Air	0.158	0.162
Combustibles	0.370	1.070
Radiation	0.436	0.440
Manufacturer's Margin	1.500	1.500
Boiler Efficiency (%)	85.623	84.931