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ABSTRACT

The extrapolation of pilot scale low NO_X burner test results to coal fired field boilers is discussed. Single burner test results are presented for three pilot scale test furnaces and two burner scales. Three burner designs are evaluated: a conventional pre-NSPS burner, a commercial first generation low NO_X burner, and a prototype second generation low NO_X burner. NO_X emissions are compared with field data from two utility wall-fired boilers equipped with low NO_X burners. A burner zone heat release parameter is used to account for differences in thermal environment between the test furnaces and field boilers.

INTRODUCTION

The reduction of NO_X emissions from industrial and utility boilers has been a concern of U.S. Environmental Protection Agency (EPA) and the major boiler manufacturers. Under a program sponsored by the U.S. EPA, Riley Stoker Corporation is evaluating the performance of a commercial second generation low NO_X coal burner. Tests have been conducted on a 100 x 10^6 Btu/hr* prototype burner in the EPA's Large Watertube Simulator (LWS) furnace operated by the Energy and Environmental Research Corporation (EERC) at their El Toro, California, test facilities.[1] The prototype burner design is based on the distributed mixing burner (DMB) concept developed in previous U.S. EPA studies.[2]

One of the objectives of this evaluation was to project the performance of the DMB in the LWS to coal fired industrial and utility boilers. To help achieve this objective, a second series of tests was conducted in the LWS on two commercial burners. The two commercial test burners included a conventional high turbulence burner, and a first generation low NO_X burner. This second test series was conducted at two burner scales: 100 and 50 x 10^6 Btu/hr.

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* Readers more familiar with metric units are requested to use the conversion factors at the end of this paper.

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Additional data, obtained from two different research furnaces and several field boilers, are also being used in the evaluation. The field data include results for two utility wall-fired boilers equipped with low NO_X burners. Both the test furnace and field results provide a systematic means of relating pilot scale burner performance to specific operating utility boilers.

TEST BURNERS

The two commercial burners selected for comparison with the DMB were the Riley Controlled Combustion Venturi* (CCV) and Flare burners. The CCV burner is a first generation commercial low NO_X burner design. The Flare burner is representative of conventional firing system designs developed prior to the New Source Performance Standards (NSPS) of 1971. A more advanced externally staged version of the CCV burner was also evaluated.

Both the CCV and Flare burners were constructed in two scales (100 and 50 x 10^6 Btu/hr). Commercial coal burners fired in field industrial and utility boilers range from 50 to 250 x 10^6 Btu/hr in scale. Burner scaling was based on constant velocity and geometric similarity. Swirl and dynamic similarity were also maintained. All of the test burners were constructed with commercial components.

Distributed Mixing Burner

The Riley version of the DMB is illustrated in Figure 1. It is a circular dual-register burner with secondary air entering through two sets of radial swirl vanes. Secondary air is supplied through two annular air passages surrounding the coal nozzle. The coal nozzle incorporates the same venturi spreader design developed for the CCV burner. This coal spreader design was refined during the tests to improve flame stability and reduce flame length under two staged combustion.

Four tertiary air ports are positioned around the periphery of the burner for staged combustion. The burner is designed to operate with 70% of theoretical air supplied through the burner throat. For the test program, the tertiary air ports were equipped with inserts to evaluate the effect of tertiary air velocity.

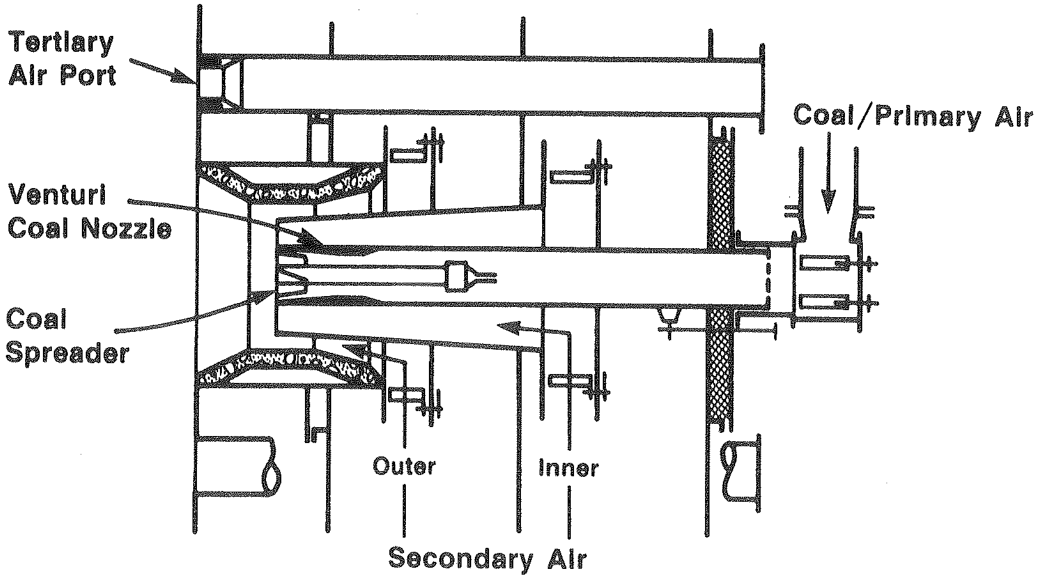

Figure 1 Riley Stoker Distributed Mixing Burner

CCV Burner

The CCV burner is shown in Figure 2. This burner was developed for retrofit into existing coal fired boilers[3]. Secondary air is supplied through a single annular flow passage and register for swirl control. The burner employs a four bladed spreader and venturi coal nozzle. NO_X control is achieved through controlled air/fuel mixing. The coal spreader imparts swirl to the primary coal air stream and divides the stream into fuel rich and lean layers before mixing with the secondary air. Tests were conducted on both a conical and straight cylindrical spreader design.

The CCV burner was also tested in a multistage burner configuration. Staging air was supplied by four tertiary air ports on the periphery of the burner, as in the DMB design.

Flare Burner

The pre-NSPS Flare burner is also illustrated in Figure 2. The Flare burner utilizes secondary air swirl control and a multivane coal nozzle to create a turbulent rapidly mixed flame.

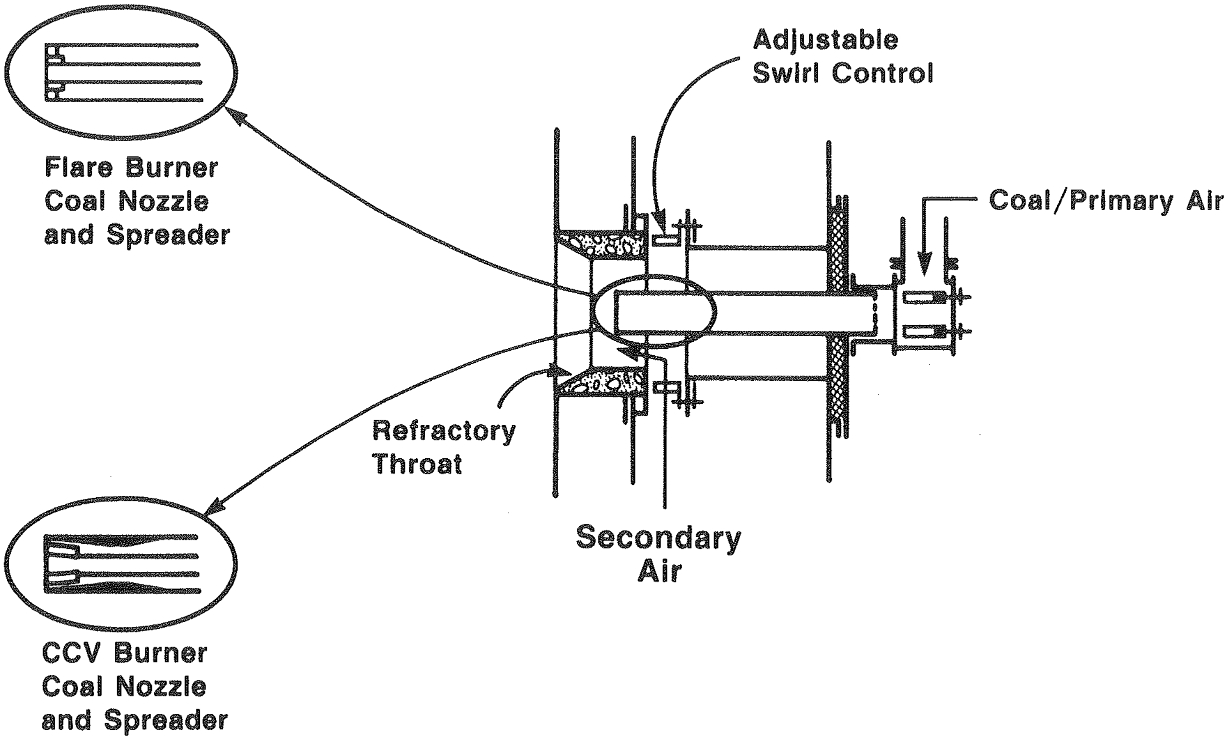

Figure 2 Riley Stoker Flare and CCV Burners*

TEST FURNACES

Both the CCV and Flare burners have been tested in two other pilot scale test furnaces in addition to the LWS. These furnaces include Riley Stoker's Coal Burner Test Facility (CBTF) and EERC's Medium Tunnel (MT) furnace. The designs of all three research furnaces are shown in Figure 3. These facilities encompass two different furnace firing capacities and two geometries.

The EPA LWS is fired with a single burner mounted on the front wall. Furnace gases exit at the top of the rear wall. The geometry is similar to that of a wall-fired boiler with a hopper bottom and a nose above the firing zone. The furnace is 22 feet deep, 16 feet wide and approximately 50 feet tall. Portions of the in-

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* Protected by U.S. Patent No. 4,479,442

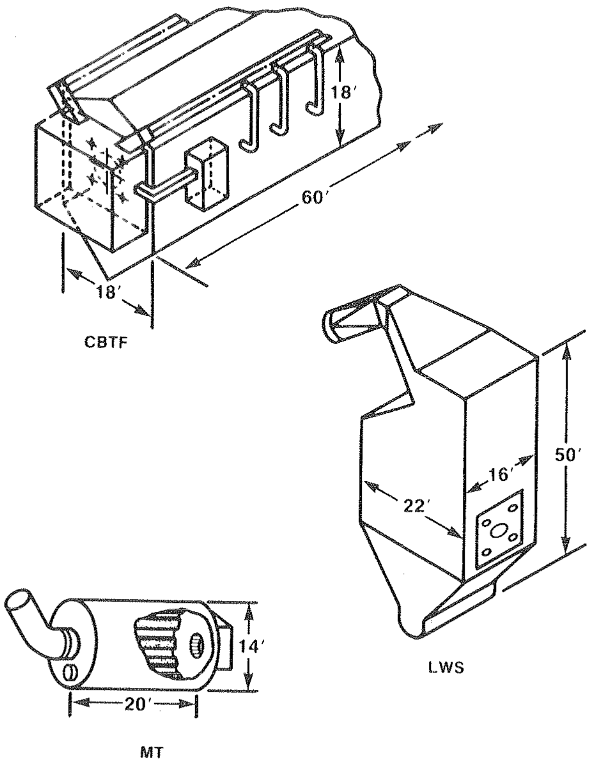

Figure 3 Pilot-Scale Test Furnaces

terior walls are insulated with refractory to simulate the environment of operating boilers. The outer surface of the furnace is cooled by water sprays.

The Riley CBTF is a horizontal tunnel furnace with the burner mounted on one end and the exhaust exiting the other end. The firing chamber is approximately 18 feet wide and 60 feet long. The straight vertical side walls extend 18 feet above the furnace hopper. Insulating refractory covers the interior of the furnace up to 40 feet from the firing wall. The firing wall is left uncovered to ensure that the wall temperature in the vicinity of the burner will be cool. A water jacket provides furnace cooling.

The EERC MT furnace is also a horizontal tunnel furnace. The MT is 14 feet in diameter and 20 feet long. Its interior walls are also partially insulated with refractory. Axial strips of refractory line the circumference of the furnace. Like the LWS, the MT is spray cooled.

The MT has a firing capacity of 50×10^6 Btu/hr. Both the LWS and CBTF are capable of testing coal burners up to 100×10^6 Btu/hr.

FIELD BOILERS

The CCV burner has been retrofitted to both single and opposed wall-fired utility boilers. Each of these designs is illustrated in Figure 4.

The single-wall-fired unit is a 400 MWe boiler equipped with 24 burners. Each burner is rated at 150×10^6 Btu/hr. The boiler fuel is an Illinois high volatile C bituminous coal. The opposed fired unit is a 360 MWe boiler with 12 burners mounted on both the front and rear walls. This boiler is fired with an eastern high volatile A bituminous coal.

Data from these field boilers provide an important link with the pilot scale results. Flare burner field data are available on field boilers ranging from 125 to 400 MWe in size.

LWS TEST RESULTS

The following burner comparison tests were run in the EPA LWS:

- Prototype DMB (100 x 10^6 Btu/hr).
- CCV Burner (100 and 50 x 10^6).
- Multistage CCV burner (100 x 10^6 Btu/hr).
- Flare Burner (100 and 50 x 10^6 Btu/hr).

Each burner was tested over a range of variables to determine conditions necessary for low NO_X operation. A Utah bituminous coal was selected to establish the operating base line for each burner design.

The performances of all burner configurations on Utah coal are compared in Figure 5. NO_X emissions of 100 x 10^6 Btu/hr burners are presented as a function of overall stoichiometry, SR_T. Unstaged CCV burner performance was determined for two spreader designs (cone and straight). Both the DMB and CCV multistage burners were staged to a burner zone stoichiometry of 70% of theoretical air. The DMB produced the lowest NO_X emissions. At the design point ($SR_T = 1.2$), DMB emissions were 200 ppm.* The Flare burner produced the highest NO_X at 600 ppm. The unstaged CCV burner produced much lower NO_X with the conical spreader (260 ppm) than with the straight spreader (400 ppm). The cone spreader produced longer (20 versus 15 feet) and narrower flames than the straight spreader design. At 20% excess air, carbon monoxide (CO) emissions were less than 55 ppm for all burner configurations.

The burners were also tested on an Illinois bituminous coal. The Flare burner produced slightly lower NO_X (580 ppm) on Illinois coal than on Utah coal, while the unstaged CCV burner (cone spreader) produced higher emissions (340 ppm). DMB NO_X emissions were measured at 220 ppm on Illinois coal.

Unstaged CCV burner performance is compared in Figure 6 at two burner scales. The 100 x 10^6 Btu/hr CCV burner is compared with the reduced scale 50 x 10^6 Btu/hr CCV burner on Illinois coal. These tests were conducted with the CCV cone spreader configuration. Both burners were designed with the same throat velocity.

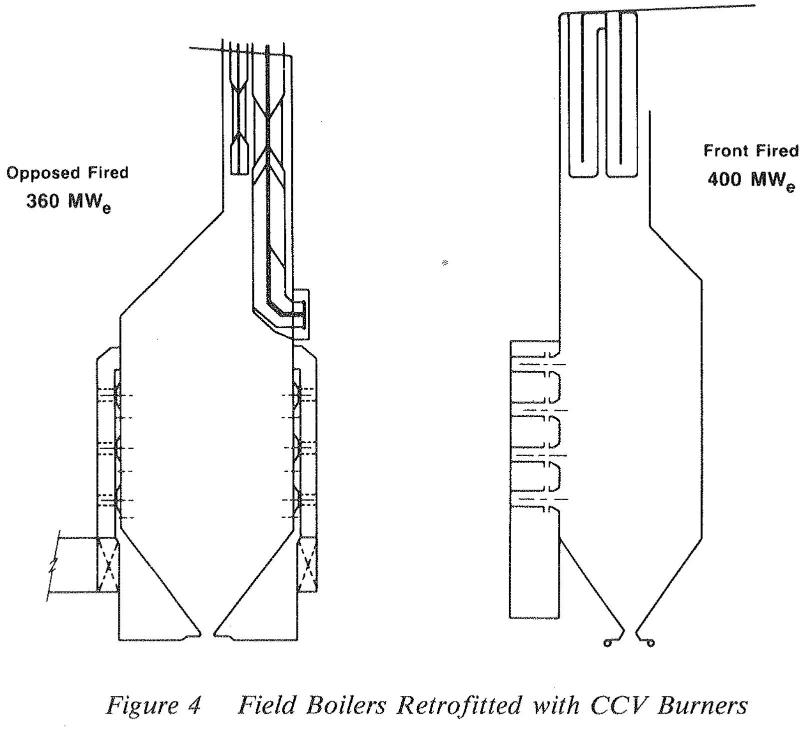

Figure 4 Field Boilers Retrofitted with CCV Burners

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* NO_X and CO concentrations referenced to 3% O_2

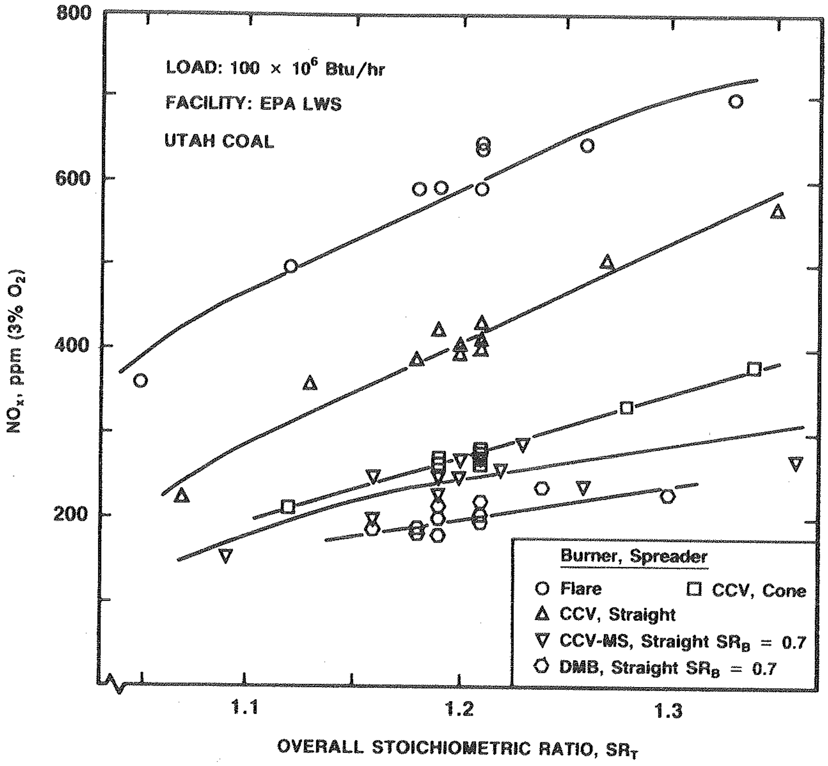


Figure 5 *NO_X Emissions from Commercial Burners in the LWS*

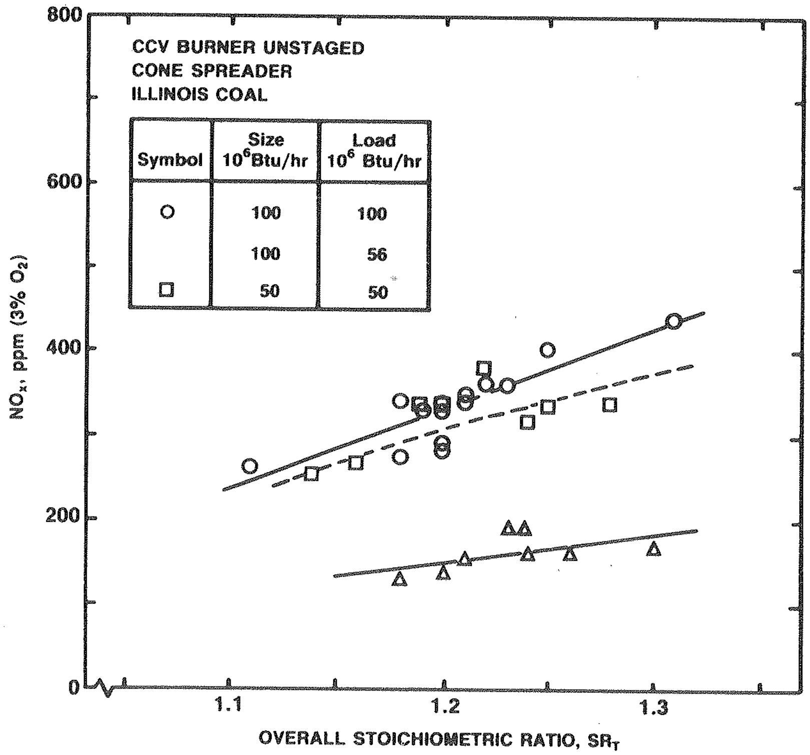


Figure 6 *Effect of Burner Scale and Load in a Single Facility*

NO_X emissions were approximately 5% (20 ppm) higher for the 100 x 10^6 Btu/hr burner than for the reduced scale 50 x 10^6 Btu/hr burner at their full load design points. At a reduced load of 56 x 10^6 Btu/hr the NO_X was approximately 60% lower for the large burner than for the smaller 50 x 10^6 Btu/hr burner.

Other studies have reported that increasing burner capacity in a fixed furnace geometry resulted in a proportional increase in NO_X emissions[4]. The full-load emission levels shown in Figure 6 are very close for both burner scales. This suggests that combustion aerodynamics, as well as thermal environment, should be considered when evaluating specific low NO_X burner designs.

EXTRAPOLATION TO FIELD BURNERS

Correlation Parameter

The reactions which control the formation of NO_X are sensitive to thermal environment. Pilot-scale furnaces and smaller industrial boilers have considerably more cooling surface area per unit volume than do large utility boilers. A correlation parameter or index is needed to characterize furnaces of different size and heat input according to their relative combustion temperature.

Riley Stoker has developed a burner zone heat release parameter to correlate field NO_X emissions from different furnaces[5]. The burner area heat release (BAHR) is defined as the total gross fuel heat input divided by the cooled surface in the main flame zone. Assuming that heat flux to a bare waterwall is similar in all furnaces, BAHR is a relative index of heat removal and temperature in the main combustion zone. Other boiler manufacturers use comparable correlation parameters for wall and arch-fired furnaces[6-8].

The lower furnace burner area excluding the ash hopper comprises the main flame zone for wall-fired boilers. Refractory covered furnace walls must be treated differently from cold uncovered waterwalls. A surface area effectiveness factor can be used to account for the reduced heat removal through refractory insulated surfaces.

BAHR is defined for wall-fired industrial and utility boilers in Figure 7. The burner zone cooled surface area extends around the front, rear, and side walls and includes an imaginary plane projected below the bot-

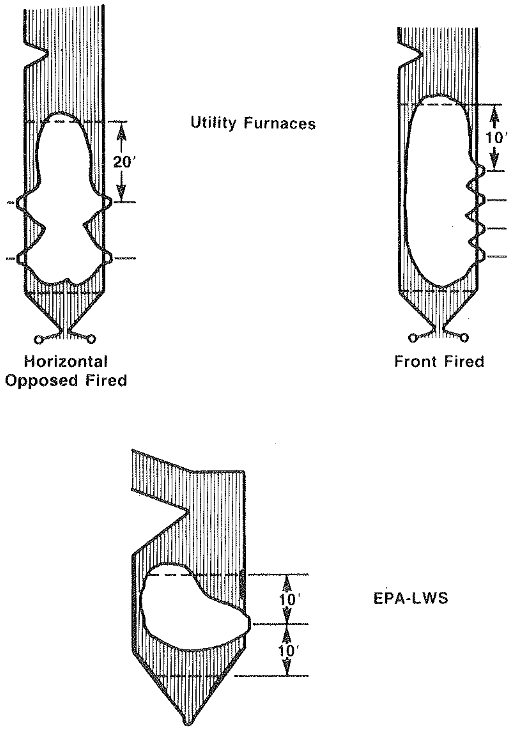
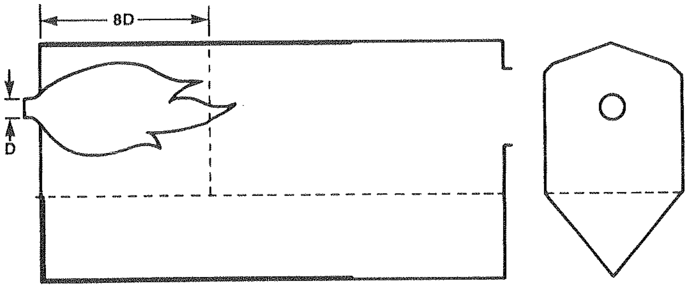


Figure 7 Definition of Burner Area in Wall-Fired Furnaces

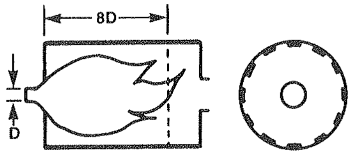
tom row of burners. The flame zone extends 10 feet above the top burner row for single-wall-fired furnaces and 20 feet above for opposed wall-fired furnaces. These are the approximate heights of the unstaged flame zones based on numerous field observations.

The definition of BAHR for the LWS, also shown in Figure 7, is based on the single-wall-fired field boiler model. All of the lower furnace walls of the LWS, except a 10 square foot section around the burner, are covered with refractory. Firebrick is used to line the hopper. These surfaces are less effective than the uncovered furnace walls and a correction factor must be applied to this surface area. A BAHR of 81 x 10^3 Btu/hr-ft^2 was calculated for the LWS at a firing rate of 100 x 10^6 Btu/hr.

The unstaged flame in the CBTF and MT furnaces was observed to be approximately eight burner throat diameters. The definition of BAHR for both of these tunnel furnace configurations is shown in Figure 8. Correction factors must also be used to determine the effective surface area in these furnaces due to the presence of refractory covered walls.



RILEY STOKER CBTF



EERC MT

Figure 8 Definition of Burner Area in Tunnel-Fired Furnaces

BAHR indexes of 133 and 82 x 10^3 Btu/hr-ft^2 were calculated for the CBTF and MT furnaces, respectively. These values are based on a firing rate of 100 x 10^6 Btu/hr for the CBTF and 50 x 10^6 Btu/hr for the MT.

Projected NO_x Emissions

The data base used in this evaluation is summarized in Table 1. It includes pilot-scale data from the CBTF and MT furnaces, as well as the LWS. Unstaged CCV burner field data are available for the cone spreader. The Flare burner data are representative for 11 different boilers.

Earlier versions of the multistage CCV burner and DMB were tested in the CBTF and in the MT. However, data for these cases were obtained under different design and operating conditions. Specifically, these differences were related to the tertiary air port design. This further emphasizes the importance of combustion aerodynamics when comparing different-scale test results.

Pilot and full scale NO_x emissions are shown in Figure 9 as a function of the burner and heat release parameter, BAHR. The emission levels are all based on 20% excess air and similar burner operating conditions. That is, burner settings were adjusted so that the flame shape for each burner was the same at each scale. DMB and multistage CCV burner operation is based on burner zone stoichiometric ratio of 0.7. All of the data in Figure 9 are for high volatile bituminous coals.

Furnace	MT	LWS		CBTF	FIELD
Burner / 10^6 Btu/hr	50	100	50	100	100 – 150
Flare	X	X	●	X	X
CCV Cone Spreader	X	X	X	X	X
CCV Straight Spreader	–	X	–	X	–
CCV-MS	O	X	–	O	–
DMB	O	X	–	–	–

X Data Used in Correlation
● Part Load Data
O Preliminary Burner Designs

Table I NO$_X$ Emissions Data Base

There is a linear relationship between NO$_X$ and BAHR for the Flare and unstaged CCV burners. Field emission levels for the CCV burner are 35 to 45% higher than LWS emissions. This difference is attributable to differences in thermal environment and multiple burner operation. The maximum flame temperature measured in the LWS under low NO$_X$ DMB operation (i.e., SR$_B$ = 0.7) was 2320°F. Furnace temperatures as high as 2800°F were measured in recent field tests on a 400 MWe boiler equipped with CCV burners[9]. NO$_X$ emissions measured in the CBTF were somewhat higher than in the LWS under comparable burner operating conditions[10].

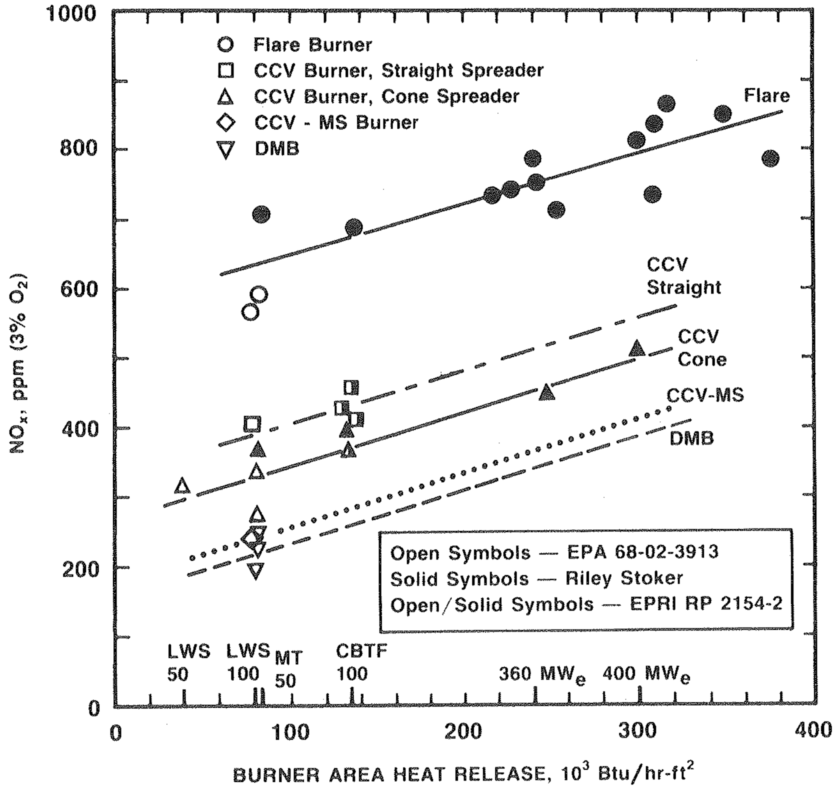


Figure 9 Correlation of Pilot-Scale and Full-Scale NO$_X$ Emissions with Burner Area Heat Release

DMB performance has been extrapolated parallel with the CCV burner correlation. NO_x emissions on the order of 360 ppm are predicted for utility scale boilers equipped with the DMB. This is a reduction of more than 50% from uncontrolled (Flare burner) emission levels.

CONCLUSIONS

One major conclusion, which can be drawn from this study, is that a burner zone heat release parameter can be used to correlate pilot scale NO_x emissions with emissions from industrial and utility boilers. The effective burner zone cooled surface area must be determined for each furnace geometry.

We predict that NO_x emissions from low NO_x burners operating in large utility scale boilers will be 20 to 45% higher than their performance in pilot-scale test furnaces. This projected increase is due to differences in thermal environment, furnace geometry, and the influence of multiple burner operation.

Caution should be used in extrapolating these test results over the full range of boiler applications. The above scale-up prediction is based on experimental work conducted on specific burner designs and furnace configurations. Factors such as variation in furnace design and combustion aerodynamics are also important considerations.

Finally, pilot-scale tests have shown that NO_x reductions of greater than 50% can be achieved with second generation low NO_x burner designs. Full scale field trials are needed to confirm this performance in an operating boiler.

CONVERSION FACTORS

Readers more familiar with metric units are requested to use the following to convert units used in this paper.

Non-metric	Times	Yields Metric
Btu	1.055	kJ
°F	5/9 (°F-32)	°C
ft	0.30	m
ft^2	0.09	m^2

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