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Project Summary

Prototype Evaluation of Commercial Second Generation Low-NO_x Burner Performance and Sulfur Capture

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Pilot scale combustion tests were conducted on a Riley Stoker second generation low-NO_x burner combined with dry sorbent injection for sulfur dioxide (SO_2) control. The burner design is based on the distributed mixing concept. Combustion tests were conducted at 100 × 10^6 Btu/hr (29 MW) in EPA's Large Watertube Simulator (LWS) test furnace. Results were obtained for three different U.S. coals and two sorbents.

Nitrogen oxides (NO_x) were reduced by up to 60% with this advanced burner design. SO_2 reductions of 50% at a Ca/S ratio of 2 were obtained with hydrated lime ($Ca(OH)_2$). Highest reductions were achieved when the hydroxide was injected through tertiary air ports on the periphery of the burner. When limestone was used as the sorbent, SO_2 capture was on the order of 35% at a Ca/S of 2.

In order to aid the scale-up of the pilot scale results to utility and industrial boilers, two commercial Riley burners were also tested at two different scales (100 and 50 × 10^6 Btu/hr). A furnace heat release parameter was used to extrapolate pilot scale NO_x emissions to operating field boilers. In addition, the Riley burner test results are compared with data from other burners also tested in the LWS test facility.

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 and Objectives

In recent years, the U.S. has turned increasingly to coal to meet its energy needs. Emission regulations for coal-fired industrial and utility boilers are directed toward limitations on nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter. NO_x and SO_2 are believed to be two of the major acid-forming precursor gases of acid precipitation. Although there is still considerable scientific debate over the relationship between emissions and acid deposition, the control of SO_2 from power plants is the major focus of proposed acid rain regulation strategies.

As part of its effort to develop emission controls for industrial and utility steam boilers, the U.S. EPA is developing Limestone Injection into Multistage Burners (LIMB) technology as a potential low cost control technology for both NO_x and SO_2. The program described here is one of several prototype-scale test programs sponsored by the EPA to evaluate the sulfur capture potential of low-NO_x burners combined with the injection of conventional sorbents. Under this program, five Riley Stoker burners were tested 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.

The objectives of this program were to (1) characterize NO_x emissions for each burner, (2) evaluate each burner for combined NO_x/SO_2 control with sorbent injection under acceptable operating conditions, (3) extrapolate the performance of the burners to field conditions, and (4) compare the results with other burner testing.

The test program was conducted in two phases. Phase 1 was performed on a single 100×10^6 Btu/hr Riley Stoker Distributed Mixing Burner (DMB). The Riley DMB is a second generation commercial scale low-NO_x coal burner. Low-NO_x operation was first established for the DMB during baseline tests. All of the adjustable burner variables were investigated to achieve low-NO_x emissions, a wide operating range, acceptable flame characteristics, and combustion efficiency. Following these initial tests the SO_2 reduction potential of the burner was evaluated. Calcium-based sorbents were injected through two different burner passages: (1) the coal nozzle, and (2) the tertiary air ports. During the Phase 1 testing, performance data were obtained for three different fuels and two sorbents.

Under Phase 2, two commercial Riley burner designs, the Flare and Controlled Combustion Venturi (CCV)* burners, were evaluated in the LWS. The Flare burner is a conventional high turbulence burner, while the CCV is a first generation low-NO_x burner. Both the Flare and CCV designs were tested at scales of 50×10^6 and 100×10^6 Btu/hr. These commercial burner tests at different experimental scales provided a link between the LWS results with other pilot scale furnaces and with actual field operation. The CCV burner was also tested under staged combustion conditions in a DMB configuration. As in the DMB design, staging air was supplied by four tertiary air ports on the periphery of the burner.

In addition to burner characterization and NO_x emissions tests, limited sorbent injection tests were conducted with the Flare and CCV burners to evaluate the effect of burner design on SO_2 reduction potential. The multistage CCV burner was evaluated on three different sorbents.

Description of Experimental Systems

Test Burners

Riley Stoker DMB

The Riley Stoker Distributed Mixing burner (DMB), shown in Figure 1, is based on design criteria developed in previous U.S. EPA studies. It is a dual register burner with secondary air entering through separate concentric air passages surrounding the coal nozzle. Swirl is imparted through adjustable radial vanes at the entrance of each passage. Although these two air passages would normally be incorporated in a common windbox, they were fed separately for this test program. This allowed independent flow measurement of each secondary air stream.

The burner was equipped with four tertiary air ports around the periphery of the burner for staged combustion. These tertiary air ports are smaller and somewhat nearer the burner in the Riley Stoker design than prescribed in the EPA's DMB criteria. These design changes increased flame stability under deeply staged combustion conditions. The tertiary air ports were also equipped with inserts to further increase the tertiary air velocity and improve downstream air/fuel mixing.

In addition, the burner incorporates the venturi coal nozzle design developed for the Riley Stoker Controlled Combustion Venturi (CCV) burner. Both coal spreader and nozzle setback position were adjustable in the test burner.

CCV Burner

The CCV burner, shown in Figure 2, was developed for retrofit into existing coal fired boilers. 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 is controlled 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 body design.

The CCV burner was also tested in a multistage, or distributed mixing burner, configuration. Staging air was supplied by four tertiary air ports on the periphery of the burner, as in the DMB design. The CCV burner was tested at two different sizes: 100×10^6 and 50×10^6 Btu/hr. The objective of these tests was to investigate the effects of heat input on NO_x emissions.

Flare Burner

The Flare burner, also illustrated in Figure 2, is designed to produce a rapidly mixed, intense stable flame. This burner utilizes secondary air swirl control and a multivane coal spreader which promotes rapid mixing of the coal stream with the secondary air. This burner produces high NO_x emissions, 1.0-1.2 lb $NO_x/10^6$ Btu, and low carbon loss in the flyash. The Flare burner was also tested at 100×10^6 and 50×10^6 Btu/hr.

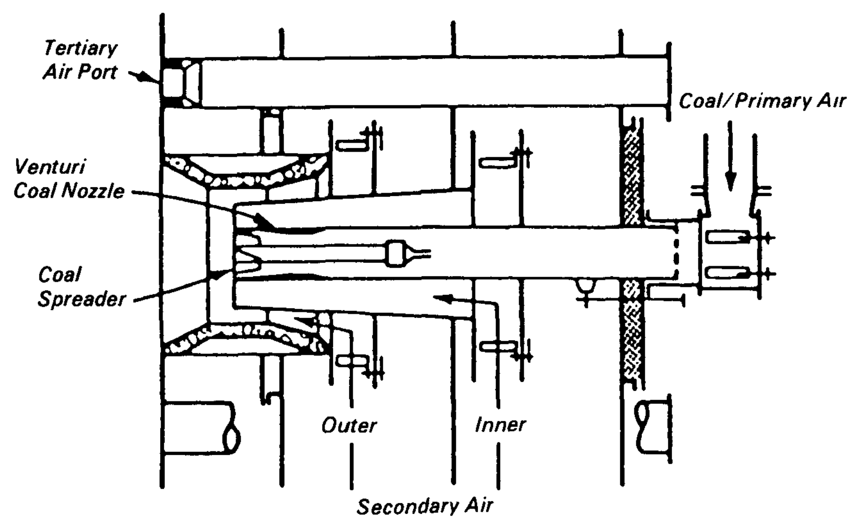

Figure 1. *Riley Stoker Distributed Mixing Burner.*

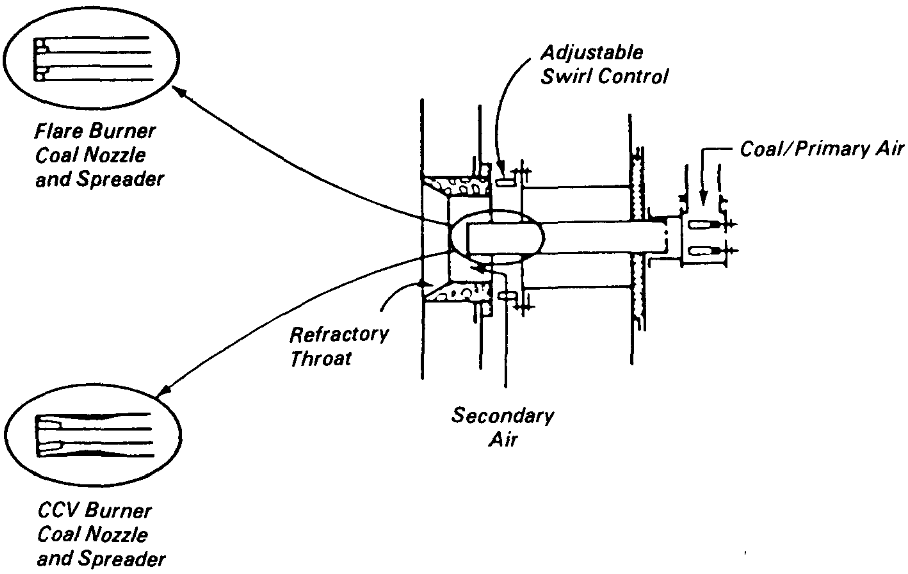

Figure 2. *Riley Stoker CCV* and Flare burners (*Protected by U.S. Patent No. 4,479,442).*

Test Facility

LWS

All of the testing under this contract was conducted in the EPA Large Water-tube Simulator (LWS) furnace, designed to simulate furnace conditions in utility boilers. The furnace is fired with a single burner mounted on the front wall. The furnace gas exit is at the top on the rear wall. With this configuration, the gas flow pattern is similar to that in a wall-fired boiler. The outer surface of the furnace is cooled by water sprays and is open to the atmosphere. In order to maintain thermal similarity with coal fired boilers, the flame zone of the furnace is refractory lined. The furnace wall near the burner, however, is uncovered to ensure that the wall temperature near the burner will be cool as in field operation.

Sorbent Injection System

The sorbent injection system was designed to feed into two locations: (1) the primary air/coal stream after the pulverizer, and (2) the tertiary air ports. Sorbent feed rate was controlled by a screw feeder. The sorbent was entrained by the compressed air and conveyed to the injection location. Sorbent was added to the primary air stream through a single nozzle downstream of the pulverizer. For injection through tertiary air ports, the sorbent was split into four streams and was injected through nozzles located on the axis of each tertiary air port.

Fuels and Sorbents

Three coals were used during the test program: Utah, Indiana, and Illinois. Utah coal was chosen as the baseline low (0.7%) sulfur coal because it had been used previously in low-NO_x burner tests supported by the EPA in the LWS. Indiana coal has also been used as a medium (2.5%) sulfur base coal in other EPA funded sorbent injection tests. The high (3.5%) sulfur Illinois coal was selected in order to relate the tests to other pilot- and full-scale burner development tests conducted by Riley Stoker. All three coals were used during the DMB tests. However, only the Utah and Illinois coals were used for the CCV and Flare burner tests.

Three sorbents were evaluated during the program: limestone (Vicron 45-3), hydrated lime, and dolomite. The sorbents were purchased, pre-milled in 50 or 100 lb (22.5 or 45 kg) sacks.

Limestone and hydrated lime were used as sorbents during the DMB test. Dolomite was tested during the CCV and Flare burner tests in addition to limestone and hydrated lime.

Test Plan

The test program was divided into two phases: (1) the DMB tests, and (2) the commercial burner tests. During Phase 1, burner performance and SO_2 reduction potential were evaluated for the Riley DMB. Burner performance includes NO_x emissions, CO emissions, carbon content in the flyash, and flame length. Initially, burner performance was evaluated based on: coal spreader position, coal nozzle position, swirl register position, degree of staging, tertiary air port size, and coal spreader design.

Following these tests, the SO_2 reduction potential of burner sorbent injection was investigated at the optimum burner configuration. Two burners were evaluated in Phase 2: the Riley CCV and Flare burners. Field test data exist for these commercial burner designs on a variety of furnace sizes and configurations. The prime objective of these tests was to vary furnace thermal environment with a constant burner design. These tests along with data contributed by Riley Stoker provided a basis for projecting NO_x emissions in the LWS to utility boilers.

Sorbent injection tests were also conducted in Phase 2 to evaluate the SO_2 reduction potential of LIMB with Riley's present commercial burner products.

Test Results

NO_x Emissions

NO_x emissions for the 100×10^6 Btu/hr test burner configurations are summarized in Figure 3 for Utah coal. Test results are presented as a function of excess air for the final DMB design configuration. The lowest NO_x emissions were achieved with the DMB, ranging from 240 ppm firing Utah coal to 290 ppm firing Indiana coal at 20% excess air. In comparison, the Flare burner produced NO_x emissions of 675 to 700 ppm at 20% excess air. This level of emissions is typical of boilers designed prior to the New Source Performance Standards (NSPS), and is representative of uncontrolled NO_x emissions.

NO_x emissions from the DMB were less sensitive to excess air than from the other burners. All of these data were taken at a burner zone stoichiometry (SR_B) of 0.7. CO emissions from the DMB were only 20 to 40 ppm. The carbon content of the flyash, a measure of combustion efficiency, was 6.2 to 10.1% based on loss on ignition (LOI). NO_x emissions from the Flare burner were sensitive to excess air, increasing 130 ppm for a 10% increase in excess air. CO

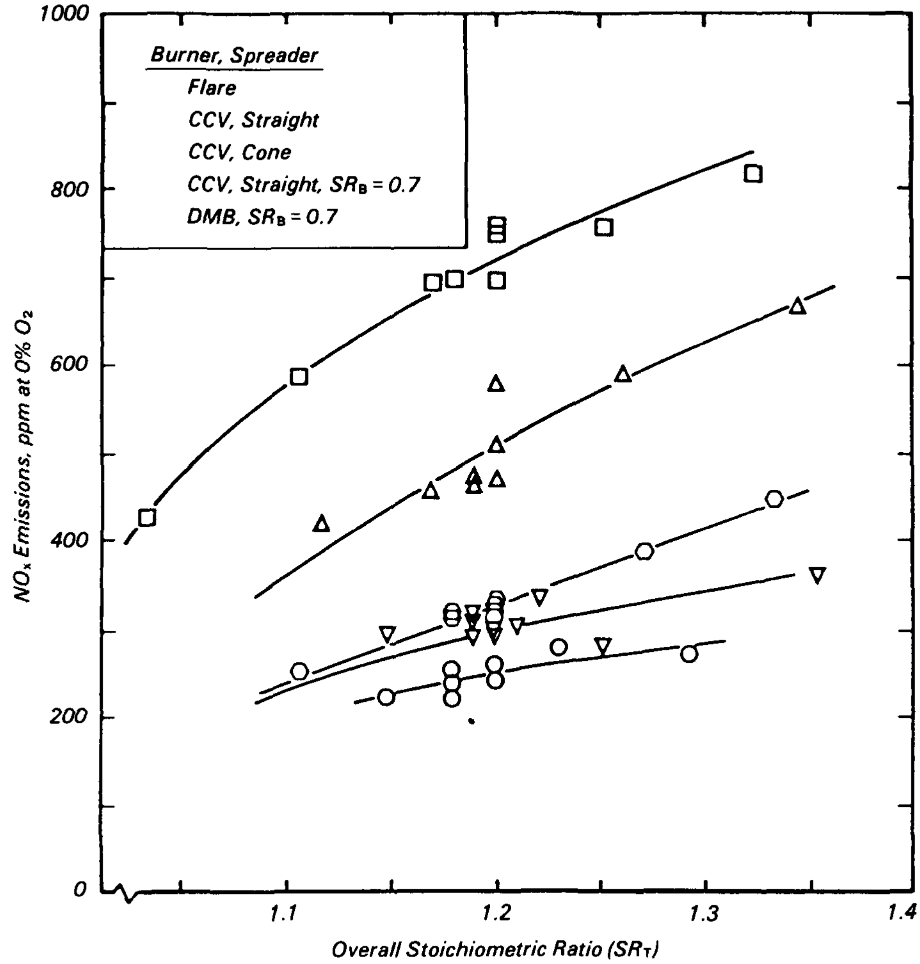

Figure 3. *NO_x emissions from Riley Stoker burners firing Utah coal in the LWS.*

emissions were less than 60 ppm while the carbon content of the flyash was only 3.9 to 5.5%.

The Riley CCV burner was tested in two coal nozzle configurations while firing the Utah coal: an expanding cone coal spreader and a straight center body coal spreader. Testing during the original CCV burner development program showed that spreader design can change NO_x emissions by a factor of two.

The cone spreader design was originally developed for the CCV burner and has been installed on three utility furnaces. Testing this spreader provided data for extrapolating NO_x emissions from the LWS to the field. The straight spreader was developed for staged combustion with the CCV burner.

The performance of the Riley DMB in the LWS is compared with various commercial burners in Table 1. NO_x emissions from Utah coal for the DMB were over 400 ppm lower than the Flare burner and 70 ppm lower than the CCV burner equipped with the cone spreader. The flame length for the DMB was the same as the baseline CCV burner and longer than the Flare burner flame. The combustion efficiency for the unstaged CCV burner can be improved with the straight spreader design at the expense of NO_x. Otherwise, the combustion efficiency for each burner design was comparable.

The DMB could also be operated over an excess air and load range similar to the Flare and CCV burners. Comparison of the performance indicates that the DMB should be retrofittable to units currently equipped with the Flare or CCV burners.

Sulfur Capture

Sulfur capture with the DMB is shown in Figure 4 as percent SO_2 capture, for the three coals, two sorbents, and three injection locations. At a calcium to sulfur molar ratio (Ca/S) equal to 2, sulfur capture ranged from an average of 32% with limestone to 50% capture with hydrated lime for each coal.

Limestone with slightly more effective as a sorbent when injected through the coal nozzle (35% capture) than when injected through the tertiary air ports (32% capture). Injection of hydrated lime through the coal nozzle was not evaluated in detail because it performed poorly, achieving 27% SO_2 capture during screening tests.

Coal composition, or more specifically sulfur content, was not a major variable in sulfur capture with the DMB. Figure 4 reveals no measurable effect of coal composition on the degree of SO_2 reduction with any of the sorbent/injection combinations. Other researchers, however, have found that coal composition can have a major effect on sulfur capture. The sulfation reaction is thought to be driven in part by the concentration of sulfur species in the flue gas.

The most favorable window for sulfur capture has been identified as 870 to 1230°C. At above 1230°C, sorbents tend to dead burn, and chemical equilibrium prohibits SO_2 adsorption if SO_2 is less than 2500 ppm. At below 870°C, SO_2 adsorption is too slow to be significant. Gas temperatures measured at the exit

Table 1. *Performance of 100 × 10^6 Btu/Hr Riley Burners Firing Utah Coal in the LWS*

	Flare	CCV Unstaged		CCV $SR_B=0.7$	DMB $SR_B=0.7$
Spreader	Flare	Cone	Straight	Straight	Straight
Minimum Excess Air, %	8	10	10	17	10
Minimum Load, % Capacity	75	60	70	–	60
Flame Length, ft (m)	14-16 (4.3-4.9)	20 (6.1)	15 (4.6)	20-21 (6.1-6.4)	20 (6.1)
Carbon Utilization, %	99.3	97.9	99.1	99.1	98.9
No_x @ 0% O_2, ppm	686	304	465	274	234

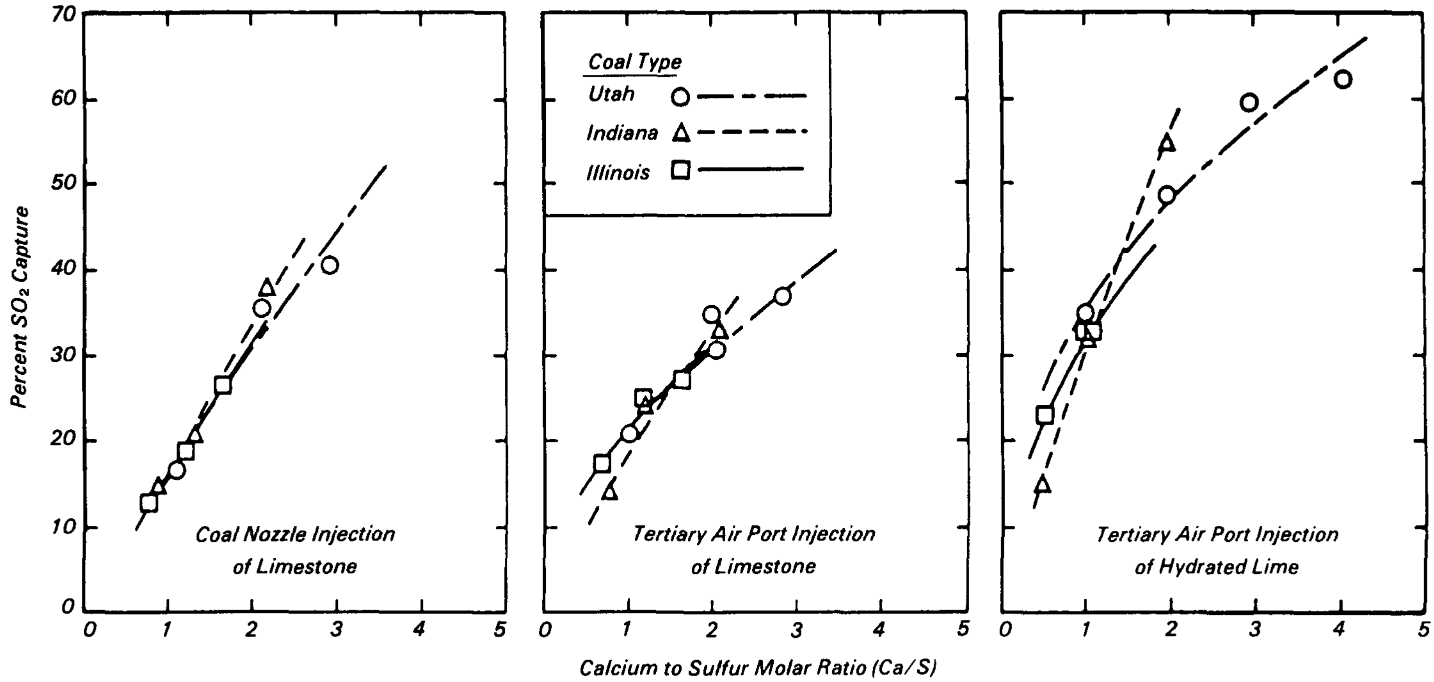

Figure 4. *SO_2 capture with the Riley Stoker DMB.*

of the LWS with the DMB were in the range of 900°C at low load and 930 to 1010°C at full load (100 × 10^6 Btu/hr). Peak temperatures as high as 1270°C were measured within the flame at full load. The effect of thermal environment on SO_2 capture was investigated by reducing the heat input to the burner to 62 × 10^6 Btu/hr. As shown in Figure 5, limestone injection SO_2 capture at low load decreased for low Ca/S ratios, but was comparable to the full load results at Ca/S equal to 3.0. The opposite was true for injection of hydrated lime: SO_2 capture at low load was comparable to the full load SO_2 capture, and increased less rapidly as Ca/S increased.

Figure 6 compares sulfur capture for all five of the Riley Stoker burners using limestone injected through the coal nozzle. At a Ca/S ratio of two, sulfur capture ranged from 22 to 35%. The highest sulfur capture was with the CCV burner staged to SR_B equal to 0.7. Sulfur capture with the DMB was slightly lower at 32%. The Flare burner achieved the lowest sulfur capture.

The effect of firing rate and burner scale on sulfur capture for the unstaged CCV burner with the cone spreader is shown in Figure 7 for Illinois coal. Sulfur capture using the 100 × 10^6 Btu/hr CCV burner at full load is compared to that for the 100 × 10^6 Btu/hr burner at part load and the 50 × 10^6 Btu/hr CCV burner at full load. Sulfur capture increased 50% from 28% capture to 42% capture by firing the smaller burner in the LWS. Sulfur capture was 38% at Ca/S equal to 2 for the 100 × 10^6 Btu/hr fired at 58 × 10^6 Btu/hr. This may be due to higher peak temperatures in the unstaged burners.

Application to the Field

Data gathered under this program were used in conjunction with data from other combustion tests of Riley Stoker burners to extrapolate LWS NO_x, emissions to operating boilers. A Burner Area Heat Release (BAHR) parameter was used to relate NO_x emissions from furnaces of various sizes and thermal environments. BAHR ranks the relative combustion intensity of different furnaces, and is similar to parameters used by other boiler manufacturers. The BAHR is defined as the total gross fuel input divided by the cooled surface in the main flame zone.

Full load NO_x emissions at 20% excess air are plotted for various burner and furnace combinations in Figure 8. Data for the Flare burner and the CCV burner with the cone spreader were available from three test facilities of interest and a number of field units. In addition to the EPA LWS, the test facilities included the Riley Coal Burner Test Facility (CBTF) and the EERC Medium Tunnel (MT) furnace. These Flare and CCV burner results were used as a basis for extrapolating NO_x emissions for the other low-NO_x burners. Unstaged CCV burner data were available from several utility boilers ranging from 360-400 MWe.

As shown in Figure 8, there is a linear relationship between NO_x and BAHR for the Flare and CCV burners. The slope of the line for NO_x versus BAHR is nearly identical for the two burners. Other low-NO_x burner performance has been extrapolated parallel to the CCV burner with the cone spreader correlation. Using this thermal scaling criteria, DMB NO_x emissions would be about 400 ppm in a large field boiler as compared to 900 ppm for the Flare burner.

During these pilot scale tests, sulfur capture resulting from injecting limestone with the coal ranged from 22 to 35%. The best results were achieved with the DMB and CCV burner, straight spreader. Injection of hydrated lime through the tertiary air ports in the DMB produced 50% SO_2 capture at Ca/S equal to 2. Injection of sorbents through

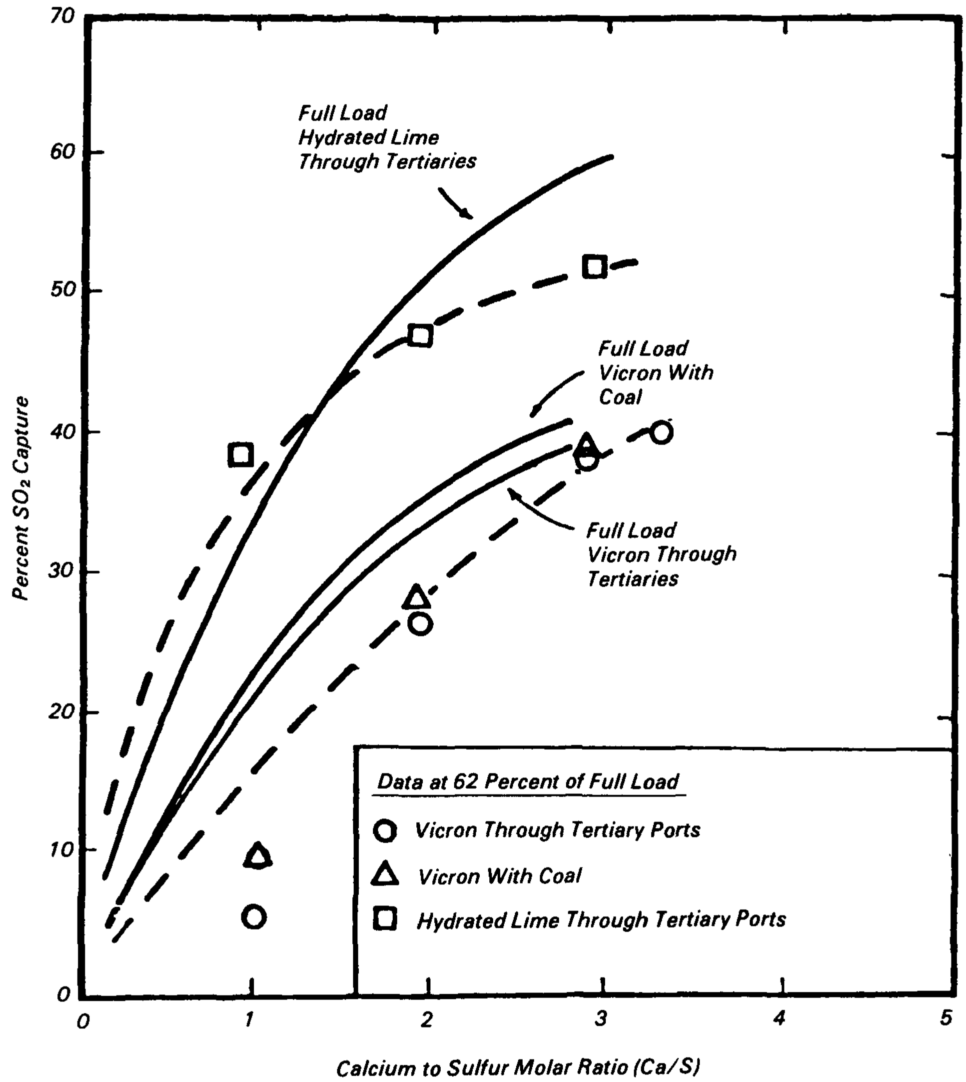

Figure 5. *Effect of thermal environment on SO_2 capture with the Riley DMB firing Utah coal.*

the tertiary air ports of the CCV-MS burner only produced 35 to 40% SO_2 reduction at Ca/S equal to 2.

The injection of sorbents in the flame zone of boilers presents problems to be addressed prior to application to the field. The increased solids loading in bottom ash and flyash will have to be accommodated. A more serious problem may be the reduction of ash melting temperatures and thus, the increased tendency toward slagging. For the LIMB process to become a viable control alternative, there must be additional understanding of the sorbent injection process, particle interaction, and the controlling mechanisms of sulfation.

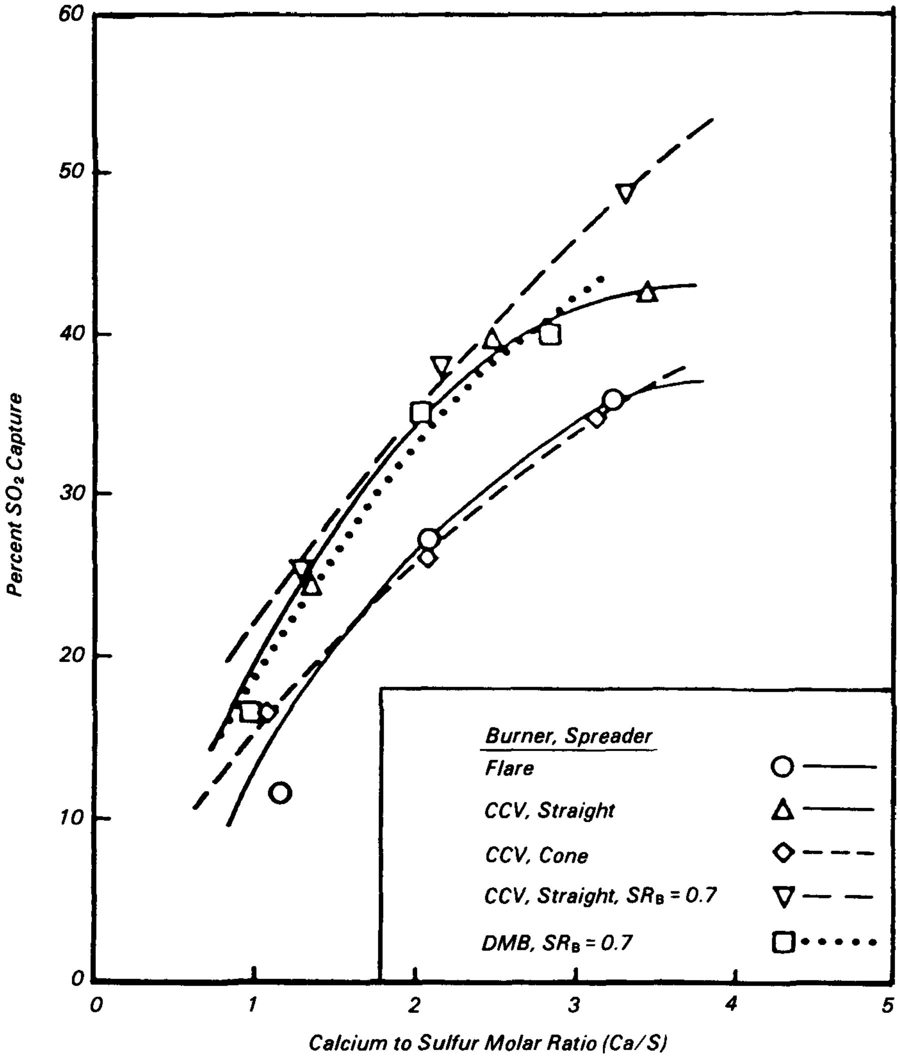

Figure 6. *SO_2 capture with Riley Stoker burners firing Utah coal.*

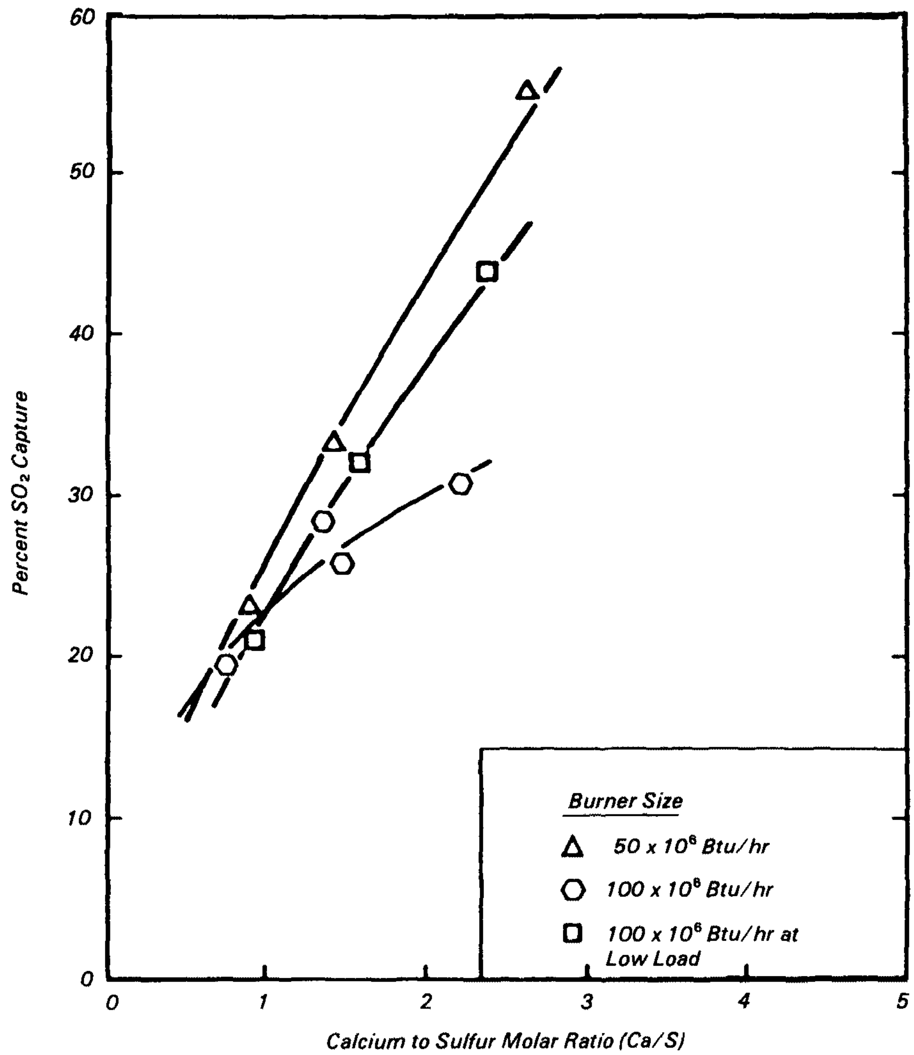

Figure 7. *Effect of thermal environment on SO_2 capture during coal nozzle injection of limestone with an unstaged CCV burner firing Illinois coal.*

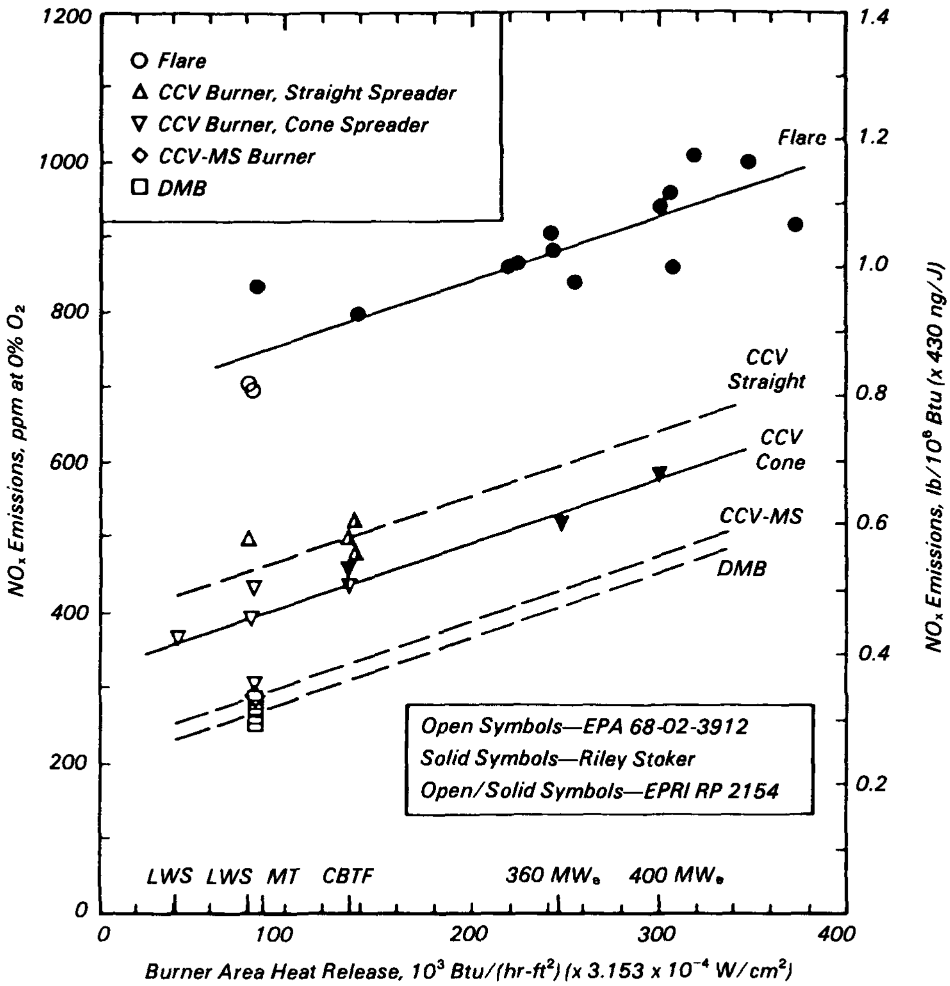

Figure 8. Projected NO_x emissions from Riley Stoker burners.

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Charles C. Masser is the EPA Project Officer (see below).

The complete report, entitled "Prototype Evaluation of Commercial Second Generation Low-NO_x Burner Performance and Sulfur Capture," (Order No. PB 86-220 407/AS; Cost: $22.95, subject to change) will be available only from:

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