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Project Summary

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

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The expanded use of coal for utility and industrial boiler applications has focused attention on the control of NO_x and SO_2 emissions from pulverized coal combustion. Various EPA programs have demonstrated the principle of staged combustion as a means of controlling NO_x emissions. Other programs are evaluating the potential for SO_2 control with the injection of calcium-based sorbents into furnace combustion chambers. Under this program, Steinmuller Staged Mixing (SM) burners were tested in EPA's Large Watertube Simulator (LWS) test facility. The objectives of the program were to provide a comparative evaluation of the SM burner in the LWS with field operation and to optimize its performance for low NO_x emissions, high efficiency, and combined NO_x/SO_2 control with sorbent injection. The experimental effort included evaluating two SM burners in the LWS using three coals and three sorbents. The evaluation of the two burners, the Weiher SM burner currently in operation in a 700 MW boiler in West Germany and a second generation SM burner, included characterization of burner performance and NO_x emissions and SO_2 reduction with sorbent injection through burner passages. The impact of the NO_x and SO_2 control techniques on ash characteristics (including slagging and fouling behavior, and SO_2/SO_3 speciation) was also evaluated.

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

The reduction of NO_x, SO_x, and particulate emissions from utility and industrial boilers has been a high-priority concern of the USEPA and all of the major boiler/burner manufacturers for several years. In fact, a number of unrelated concurrent efforts have been and are being conducted to develop low-NO_x burners. This program represents one portion of an effort by the EPA to compare the results of these individual studies and identify the most promising avenues for further success. Under this program, Steinmuller (LCS) staged mixing (SM) burners were tested in EPA's Large Watertube Boiler Simulator (LWS) test facility. Although LCS does not build boilers in the United States, they have already tested a burner with outboard staged air ports in a 700 MW boiler, Weiher Unit III, in Germany. Sorbent injection is currently being tested in the same boiler to assess the potential for combined NO_x/SO_2 control. Tests of a scaled-down Steinmuller low-NO_x burner in the LWS will provide EPA with a relative comparison with combined low-NO_x/SO_x operation in a large boiler.

Two LCS SM burners were evaluated in EPA's LWS for combined NO_x/SO_2 reduction potential. A scaled-down 100 x 10^6 Btu/hr SM burner, matching the design parameters of the 235 x 10^6 Btu/hr burners installed at the Weiher III boiler, was evaluated in the first phase of testing to establish a basis for comparing burner performance in the LWS with an operating boiler. The SM burner design was then optimized, resulting in the SM-II burner, by incorporating advanced LCS design concepts in a second phase of testing. These advanced designs included modifications of the secondary and tertiary air velocity, tertiary air location, and the coal nozzle configuration. These SM burners were tested with three coals, including that used at the Weiher boiler in Germany. SO_2 reduction potential by the injection of calcium-based sorbents through burner passages was evaluated with three sorbents. Detailed measurements were performed at selected conditions to characterize burner performance.

The basic configuration of the Weiher SM test burner has four passages. Coal and primary air enter the burner vertically upward and are injected through an annular passage to the burner exit. Coal is distributed uniformly by accelerating the coal and primary air mixture from a low velocity region at the head of the burner into the annular passage. The basic SM configuration does not use an impeller at the exit of the coal annulus, so that the coal and primary air flow is purely axial. A small portion of combustion air is supplied through the large central core passage. This core air cools the ignition equipment, establishes bluff body recirculation to provide stability at the base of the flame, and supplies additional oxygen at the ignition point to improve stability. Secondary air is supplied through a single annulus around the coal pipe. Swirl is varied in the secondary air passage by a block of fixed-angle vanes that are movable to alter the distribution of air either passing through or around the vanes. Air to complete the combustion process is provided through four tertiary ports around the burner exit.

The optimization tests of the SM burner utilized the same basic configuration. The advanced concepts evaluated during the second phase of tests included:

- Secondary passage insert to increase secondary air velocity.
- Tertiary air port location (radial distance from burner).
- Inserts in the tertiary ducts to increase velocity.
- Variable annular coal splitter to vary the coal/primary air distribution.
- Venturi insert in the annular coal nozzle

The secondary insert, designed to increase the secondary air velocity by about 30 percent, was used throughout the second phase optimization tests in an arrangement termed the SM-II burner.

Three fuels and three sorbents were used during this test program. The coals tested (all high-volatile bituminous) were from Utah, Indiana, and the Saar region of Germany. Both the Utah and Saar coals are low in sulfur, 0.73-0.96 and 0.72-0.87 percent, respectively. The Indiana coal has a medium level of sulfur (1.35-1.46 percent). The Indiana and Utah coals have been used previously in burner development and sorbent injection studies, and thus provide a link to a broad data base. Two of the sorbents were limestones and the third was a hydrated lime. The limestones ($CaCO_3$) included Vicron 45-3 and Rheinisch-Westfaelische Kalksteinwerke (RWK) $CaCO_3$, prepulverized to a median particle size of 9.8 and 20 μm, respectively. The hydrated lime was also from RWK with a mass median diameter of 4 μm.

Burner Performance and NO_x Emissions

Weiher III SM Burner

The Weiher SM burner is very simple, having a single adjustable parameter, the secondary air swirler. The position of the swirler, and resulting degree of secondary air swirl generated, had little effect on emissions over most of its range; however NO_x emissions increased about 100 to 550 ppm* at the maximum swirl position. For stable full-load operating conditions, the flame length was about 21 ft (6.4 m) with the ignition point at the burner exit. General operation of the test burner was observed to be typical of the SM burners at Weiher.

Emissions from the Weiher SM burner were sensitive to both the degree of staging and excess air levels. The rate of decrease in NO_x emissions ranged from 5 to 7.5 ppm/1 percent theoretical air change in the burner zone stoichiometry. The effect of excess air change was slightly greater, 9 to 15 ppm decrease in NO_x for each 1 percent theoretical air decrease. At nominal design point conditions (SR_B = 80% TA, SR_T = 125% TA), NO_x emissions were 415, 450, and 570 ppm for Utah, Saar, and Indiana coal, respectively.

*Note All emissions are reported on a dry basis and are corrected to 0 percent O_2.

SM-II Burner

The SM-II burner was optimized using both the adjustable burner parameters and hardware modifications to the burner geometry. The effect of each parameter evaluated is summarized below.

Secondary Air Swirl. The position of the swirl vane device, and the resulting degree of secondary air swirl generated, had negligible effect on emissions as long as the flame was stable. However, decreasing swirl resulted in progressively increasing flame length and flame detachment.

Core Air Flow. Increasing core air flow generally decreased NO_x emissions with no significant effect on combustion efficiency as measured by CO levels. At the highest flow through the core air passage, flame length and detachment increased.

Secondary Air Velocity. Increasing the secondary air velocity, by installing an insert in the throat of the Weiher SM burner, had no significant effect on emissions. Flame stability was improved to allow stable operation at lower burner zone stoichiometry.

Tertiary Port Location. Of the two locations tested, the set of tertiary air ports farther from the burner centerline produced lower NO_x emissions, with the difference becoming greater at lower burner zone stoichiometry.

Tertiary Air Velocity. Tertiary velocity was varied, using inserts in the ports that increased the velocity by about 50 percent. For both the inner and outer port locations, the higher tertiary air velocity (i.e., smaller port diameter) produced lower NO_x emissions. Again, the difference in emissions became greater as staging was increased.

Coal Nozzle Design. Two inserts for the annular coal nozzle were evaluated. A variable blocking device, that divided the coal stream and increased the primary velocity, produced a narrow flame that reduced NO_x under unstaged conditions. Staging this configuration significantly increased CO emissions. This device also resulted in a much higher pressure drop across the coal nozzle, which caused operational problems for the pulverizer and primary air system. A venturi-shaped insert increased NO_x emissions along with flame standoff. Best overall performance was achieved with the baseline annular coal nozzle.

The optimized configuration of the SM-II burner included the following hardware:

- Secondary air insert.
- Baseline annular coal nozzle.
- Outer tertiary port location.
- Small-diameter, high-velocity tertiary air ports.

This configuration produced stable full-load flames about 21 ft (6.4 m) long. NO_x emissions at full-load design point conditions (SR_B = 80% TA, SR_T = 125% TA) for this optimized SM-II burner were 370, 370, and 500 ppm for Utah, Saar, and Indiana coals, respectively. Emissions from the SM-II burner were also sensitive to burner zone stoichiometry and overall excess air. The nominal rate of change in NO_x with burner zone stoichiometry was about 10 ppm/1 percent theoretical air change. The effect of excess air was less, about 6.5 ppm decrease in NO_x for each 1 percent change in excess air.

Comparison of Weiher SM and SM-II Burners

Overall performance of the basic Weiher SM burner was improved with the optimum hardware. NO_x emissions were lower at design point conditions, and combustion efficiency was higher. The range of operation, including excess air and turndown, was maintained if not improved. Range of operation could probably be further improved by design changes in secondary swirl generation. Increasing swirl would allow staged operation over the entire load range with stable attached flames.

The NO_x emissions from the optimum SM-II design were more sensitive to burner zone stoichiometry than the Weiher burner, while the effect of excess air on emissions was much less for the optimized burner. Combustion efficiency with Saar coal was improved with the optimized burner

Sulfur Dioxide Control

Weiher SM Burner

The SO_2 reduction tests with sorbent injection for the Weiher SM burner utilized three sorbents, three injection locations, and three coals. The sorbents, two limestones and a hydrated lime, were injected with the coal at the pulverized outlet, through nozzles on both the axis of the inner tertiary air ports and the axis of the outer tertiary ports For the Weiher SM burner configuration, tertiary air flowed through the inner set of ports only. Most of the SO_2 tests were conducted with the Saar coal to obtain data for comparison with sorbent injection tests planned at the Weiher III boiler.

The two limestone sorbents, the Vicron and the RWK $CaCO_3$, achieved similar SO_2 reduction when injected with the Saar coal, 35 and 32 percent at a Ca/S molar ratio of 2, respectively. Sulfur capture with RWK hydrated lime injected with the coal was lower, particularly for Ca/S molar ratios greater than 2. Greater SO_2 reduction was achieved by injecting the hydrated lime through either the inner or outer tertiary ports, with 49 and 54 percent capture at a Ca/S molar ratio of 2, respectively. Capture with the Vicron and RWK limestones was again similar for injection through the inner tertiary air ports, about 32 percent at a Ca/S molar ratio of 2. However, injection through the outer tertiary ports resulted in substantially higher capture with the Vicron limestone (40 percent at a Ca/S molar ratio of 2) than with the RWK limestone (29 percent).

The trends for SO_2 reduction were similar for the two U.S. coals with the Weiher burner. Highest capture was achieved with the RWK $Ca(OH)_2$ injected through the inner tertiary ports, with 49 percent capture at a Ca/S molar ratio of 2 for Utah coal and 35 percent for Indiana coal. Injecting Vicron through the tertiary ports yielded higher SO_2 capture than injection with the coal, about 35 to 30 percent, respectively, for both U.S. coals.

SM-II Burner

The potential for SO_2 reduction for the SM-II burner was determined with two sorbents, Vicron limestone and RWK $Ca(OH)_2$, through three injection locations: with the coal, through the inner tertiary ports, and through the outer tertiary ports. Sorbent was injected only through the tertiary ports through which the air flowed.

The trends for all three fuels with the optimized SM burner were similar, with the best performance in terms of SO_2 capture achieved by injecting RWK $Ca(OH)_2$ through the outer tertiary ports and with little difference in the effectiveness of injection location for the Vicron limestone. Levels of SO_2 capture at a Ca/S molar ratio of 2 for the higher sulfur content Indiana coal were 50 percent with the RWK $Ca(OH)_2$ through the outer tertiary ports, 33 percent with Vicron through the outer tertiary ports, and 30 percent with Vicron injected with the coal. For each combination of sorbent and injection configuration, sulfur capture is an average of about 4 percent higher with the higher sulfur content Indiana coal than with the Utah coal. Intuitively, an effect of composition (sulfur content, in particular) would be expected. The sulfation reaction would be thought to be driven in part by the concentration of sulfur species.

Comparison of Weiher SM and SM-II Burners

In general, the trends in SO_2 capture for various sorbent and injection locations for the Weiher and optimized SM burner were similar. The most effective sorbent with Saar and Utah coals was the RWK hydrated lime injected through the outer tertiary ports for both burners. For the Weiher SM burner, limestone injection through the tertiary ports achieved SO_2 reduction comparable to the hydrated lime. The injection location of the limestone sorbent had some effect on capture achieved with the Weiher burner, but essentially no effect with the optimized burner. Tertiary air velocity, varied using inserts during tests with the optimized burner, did not measurably affect capture. Coal type, or composition, had little effect on SO_2 capture by sorbent injection for the optimum and Weiher burners. Operating variables that had negligible effect on SO_2 reduction with sorbent injection for both burners included degree of staging and firing rate.

During the Weiher SM burner tests, NO_x emissions increased when limestone was injected into the mill with the Saar coal. The increase in NO_x appeared to be proportional to the sorbent injection rate, ranging from 5 to 15 percent over the baseline NO_x emissions as sorbent flow increased. This phenomenon occurred with the U.S. coals also but to a much lesser degree. NO_x emissions did not change measurably during the sorbent injection tests with the optimized SM burner.

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The complete report, entitled "Prototype Evaluation of Commercial Second Generation Low-NO_x Burner Performance and Sulfur Dioxide Capture Potential," (Order No. PB 86-122 009/AS; Cost: $22.95, subject to change) will be available only from:
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