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Project Summary

Evaluation of Internally Staged Coal Burners and Sorbent Jet Aerodynamics for Combined SO_2/NO_x Control in Utility Boilers: Volume 1. Testing in a 10 Million Btu/Hr Experimental Furnace

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As part of EPA's Limestone Injection/Multistage Burner (LIMB) program, testing was conducted on a 2.9 MWt (10 million Btu/hr) experimental furnace to explore the potential for designing utility coal burners to achieve reduced NO_x emissions through staging of the combustion air internally within the burner. Such internal staging would avoid the need for external tertiary air ports, and thus simplify the retrofit of such a low-NO_x burner into existing utility furnaces. Testing also addressed the potential for SO_2 removal by injecting calcium-based sorbents (such as limestone) in conjunction with coal-fired internally-staged burners, for combined SO_2/NO_x control. Particular emphasis was placed upon understanding the sorbent jet design parameters which could improve the activation and SO_2 removal performance of sorbents, by controlling sorbent heating rate and the peak temperature seen by the sorbent. The sorbent jet testing considered injection both near the burners (using large, double concentric jets), and under upper-furnace conditions, remote from the burners.

Testing of alternative internally-staged burner designs showed that—if a particular retrofit situation offers the flexibility to increase the burner throat diameter, in order to reduce velocity—NO_x emissions of 300-500 ppm appear achievable with two secondary air channels and coal nozzle modifications. This emission represents approximately the desired 50-60 percent reduction in the emissions (typically 500-750 ppm) characteristic of burners built prior to promulgation of EPA's initial New Source Performance Standards (NSPS) for large boilers. However, where there is no flexibility to increase the throat and reduce velocity, then additional steps (e.g., a baffle in the outer secondary air channel to direct the air away from the fireball) are necessary to reduce NO_x to 400-550 ppm, approaching the reduction objective.

Sorbent jet testing confirmed that the peak temperature seen by the sorbent is a key variable in determining sorbent reactivity. A peak temperature of 1230-1290°C (2250-2350°F) appears to be optimum for all five sorbents tested (a limestone, a dolomite, two atmos-

pheric hydrates and a pressure hydrate). At this peak temperature, the most reactive sorbent (the pressure hydrate) gave 80% SO_2 removal at a Ca/S molar ratio of 2, and the least reactive (the limestone) gave 30%. The apparent effect of sorbent heating rate was not consistent over the full range of temperatures tested, but at the optimum peak sorbent temperature, the higher heating rate (higher sorbent jet velocity) consistently produced somewhat higher SO_2 removals. The experimental furnace was too small to permit an effective test of whether double concentric jets (with an annular air jet surrounding the sorbent jet) could protect the sorbent from overheating during near-burner injection. Testing of controlled sorbent precalcination followed by immediate injection into the furnace showed little clear benefit of close-coupled precalcination.

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

LIMB is a technology being investigated to achieve simultaneous SO_2 and NO_x control for existing coal-fired utility boilers. The process envisions the use of calcium-based sorbent to achieve intermediate levels of SO_2 removal (50-60 percent), and staged burners for NO_x reduction, for retrofit applications as a potential component of an acid rain control strategy.

Some staged burners which have been tested involve the use of external tertiary air ports to delay fuel and air mixing. In some cases, it could be difficult to retrofit such external ports into existing boilers, due to structural or other constraints. An objective of the current study was to investigate burner design approaches which could achieve the benefits of air staging without external ports; i.e., with the staging *internal* to the burner, in a manner which would facilitate retrofit.

The sulfur capture performance of a sorbent is dictated by the surface area it develops upon calcination, upon its residence time at sulfation temperature, and upon its dispersion in the furnace. Injection near the burner would provide the greatest residence time and the best dispersion, but could subject the sorbent to high temperatures which would greatly reduce its surface area/reactivity. Initial testing in this study focussed on sorbent injection near the internally-staged burner, including use of large, double concentric jets which provide a sheath of annular air around the sorbent jet to protect it from high temperatures. Later testing focussed on conditions representative of upper-furnace injection, remote from the burners. The sorbent jet testing addressed the ability to improve sorbent surface area/reactivity through control of peak temperatures seen by the sorbent, and sorbent heating rate.

Experimental Equipment

The testing was conducted on a 2.9 MWt (10 million Btu/hr) experimental furnace, referred to as the Small Watertube Simulator (SWS). The furnace was a horizontal cylinder which could be fired from one end with coal, oil or gaseous fuel. For the internally-staged burner tests, the modified burner to be tested was mounted on the firing end of the furnace. For the sorbent jet testing, the hot gas flow field was generally established using a series of gas-fired burners at the firing end, with the jet to be tested being mounted through the firing wall (co-flowing jet).

Results

Internally Staged Burners for NO_x Reduction

If an internally staged burner is to be retrofit into an existing boiler, the ease with which reduced NO_x emissions can be achieved will depend upon the flexibility which the host boiler provides for reducing the secondary air velocity through the burner (e.g., by increasing burner throat diameter).

If the boiler permits retrofit of an enlarged-throat burner, then NO_x control capabilities are suggested in Figure 1. The secondary air velocity utilized in the SWS testing used to generate that figure was generally 24 m/sec (80 ft/sec), which is relatively low. Two types of burner modifications were used to obtain the NO_x performance indicated in the figure, beyond the reduction in velocity:

1. dual secondary air channels were used. (By comparison, the original pre-NSPS burner to be replaced in retrofit situations will often have only a single secondary air channel.)
2. alternative coal nozzles were used t promote fuel/air staging.

The alternative coal nozzles whic appeared to be the most effective, ar which also gave good flame stability ar combustion performance (CO < 6 ppm), were an axial swirler and a splitte Also effective was dense-phas coal/primary air injection (utilizing 0.2 k of primary air per kg of coal, about 10' of the normal ratio). Dense-phas transport reduced the size of the co pipe in the center of the burner, thu permitting further reduction of th secondary air velocity to 18 m/sec (6 ft/sec). Dense-phase transport might n be compatible in some cases with the a requirements for existing coal mills.

The burner modifications represente in Figure 1 were capable of reducing N(emissions to 300-500 ppm (dry, 0% O; This emission with internally-stage burners is comparable to that achieved the SWS with a low-velocity low-N(distributed mixing burner having extern air ports. By comparison, pre-NSF burners without staging typically hav emissions of 500-750 ppm.

Figure 2 gives results where the retro does not permit enlargement of th throat, and the secondary air veloci must thus remain at the levels (arou 58m/sec, or 190 ft/sec) typical of pr NSPS burners. This would be minimum-flexibility situation. Burn modifications identical to those used t the low-velocity case (dual secondary channels, specific alternative cc nozzles) result, in the high-velocity cas in NO_x emissions of 650-850 ppm (upp shaded area in Figure 2). The emissions are comparable to the ran observed in unmodified pre-NSF burners. However, when a conical baf is installed on the lip of the inn secondary air sleeve—diverting t secondary air in the outer channel aw from the fireball, thus delaying fuel/ mixing—significant additional N reductions are achieved. Emissions th fall to 400-550 ppm (lower shaded area Figure 2).

A limestone (Vicron 45-3) was inject at several locations in the burner zo near the high-velocity burner: with t primary air/coal, with the secondary and through external ports near t burner (at different injection velocities). all cases, calcium utilizations were l (about 10%, corresponding to 20% S removal at a Ca/S molar ratio of 2). T low removal was probably due to therr or coal ash deactivation of the sorbe

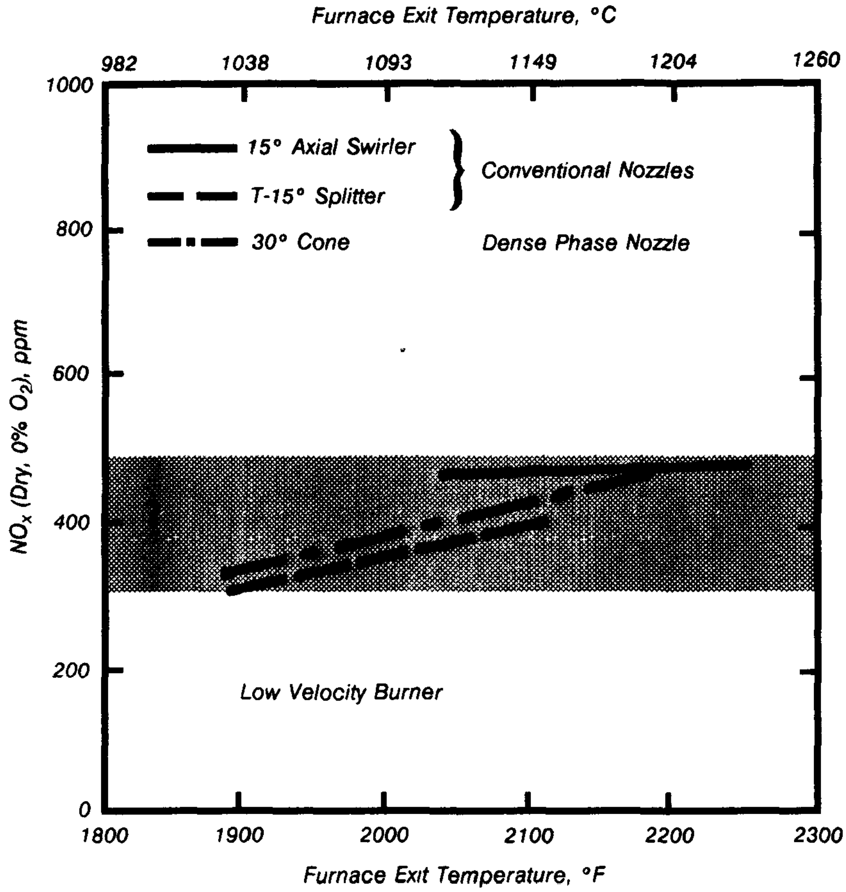

Figure 1. *Summary of NO_x emissions from experimental internally staged burners operating at low velocity (flexibility for throat enlargement): effect of alternative coal nozzles.*

Thus, it was apparent that the sorbent would have to be injected either remote from the burners, or through jets which would help protect it from this deactivation.

Sorbent Jet Investigations— Double-Concentric Jets

The first phase of the sorbent jet investigations addressed relatively large double-concentric jets, which, it was hoped, might provide the necessary protection of the sorbent to permit injection near the burner. In this testing, the variables studied included the diameter of the annular air jet, and the velocities of the annular air jet and the inner sorbent jet. SO_2 reductions were typically 28-38% at Ca/S = 2. However, these large jets introduced such a large mass of air that they significantly reduced the background temperature of the SWS furnace; this thermal effect dramatically affected the peak temperature and the time/temperature history seen by the sorbent, in a manner unique to the SWS experimental system. As a result, it is not possible to assess from these results how effectively double-concentric jets might in fact protect the sorbent in a large-scale boiler. Because of the impact of the jets on SWS operating conditions, these tests showed no consistent effect of jet parameters (e.g., jet velocities) on capture performance.

Sorbent Jet Investigations— Small Jets

The small sorbent jets tested were primarily 5-cm (2-in.) diameter single-pipe jets, without the annular air jet present in double-concentric jets. The small jets were tested at conditions (temperatures) representative of injection into the upper furnace, remote from the burners. These small jets gave higher and better-controlled sorbent heating rates, permitting a better study of heating rate effects on sorbent activation. The test matrix for these tests was designed to permit separation of the effects of sorbent peak temperature and heating rate. Peak sorbent temperature was controlled by adjusting the SWS background temperature. Heating rate was controlled by adjusting both the jet velocity and the background temperature; a doubling of the velocity doubles the heating rate, all other factors being equal.

The effect of peak sorbent temperature for five different calcium-based sorbents at constant heating rate is shown in Figure 3. As expected, the SO_2 capture for all of the sorbents tested was found to be sensitive to peak temperature, with the higher-reactivity sorbents showing the greater sensitivity. Maximum SO_2 capture was found with peak sorbent temperatures of 1230-1290°C (2250-2350°F). Heating Rate 1 in the figure corresponds to a calculated 8,000°C /sec (15,000°F/sec), while Heating Rate 2 is a calculated 19,000°C/sec (34,000°F/sec). As in other studies, pressure-hydrated dolomitic lime ("Type S" in Figure 3) and pulverized dolomite were found to be the most reactive of the sorbents tested; calcitic limes which had been hydrated at atmospheric pressure (Colton and Longview) had somewhat lower reactivity; and pulverized limestone (Vicron) had the lowest reactivity.

At constant peak sorbent temperature, the effect of (calculated) heating rate was not consistent over the full range of temperatures tested. But at the temperatures producing maximum capture (1230-1290°C), the higher heating rate consistently produced higher SO_2 removals. Sulfation modelling studies indicate that this increase in capture cannot be explained solely on the basis of the different time/temperature histories experienced by the sorbent in the different tests; thus, the differences in heating rate might in fact have been playing a role.

Sorbent samples were taken at the furnace exit for surface area analysis, to determine if in fact the higher heating rates were generating higher surface areas. These test were made with no SO_2 doping of the natural gas being burned in the SWS, so that no area loss would be occurring due to the sulfation reaction. As expected, the surface areas tended to decrease with increasing peak temperature. But there was no observable influence of heating rate on the final surface area of sorbent at the furnace exit. This suggests that, if heating rates did create different areas early in the jet,

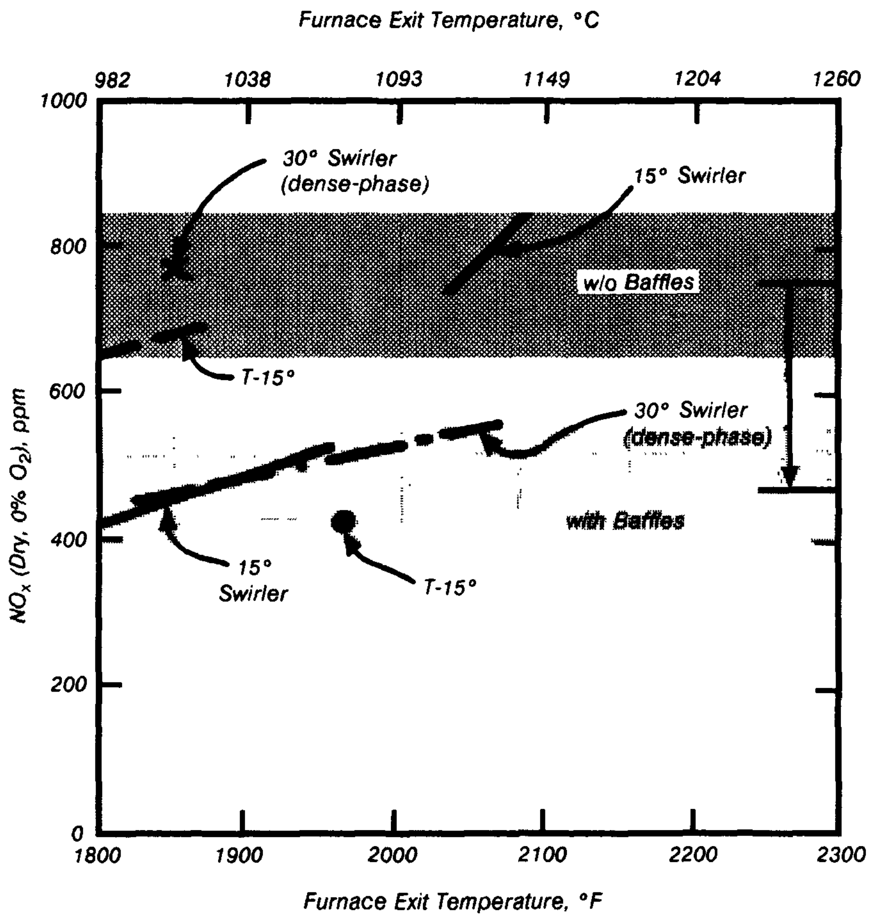

Figure 2. *Summary of NO_x emissions from experimental internally staged burners operating at high velocity (no flexibility for throat enlargement): effect of baffles in secondary air channel.*

these differences were gone by the time the sorbent reached the furnace exit.

Testing of a Close-Coupled Precalciner

A calcination vessel was installed near the SWS, to determine if a highly active sorbent could be generated by controlled, high-heating-rate precalcination of the sorbent, followed by immediate injection of the calcined material into a furnace before the surface area could decay. Four different versions of the precalciner were used to study the effects of calciner temperature and residence time, and the possible influence of chromium in the calciner refractory as a reactivity promoter. The SO_2 capture results did not show any improvement with use of the calciner, compared to allowing the sorbent was allowed to bypass the calciner, except in one case. Surface area measurements on sorbent taken from both the jet issuing into the SWS, and the SWS exit, showed that the sorbent was only partially calcined in the precalciner, with final calcination being completed in the furnace. Surface area at the end of the furnace was the same with or without the precalciner.

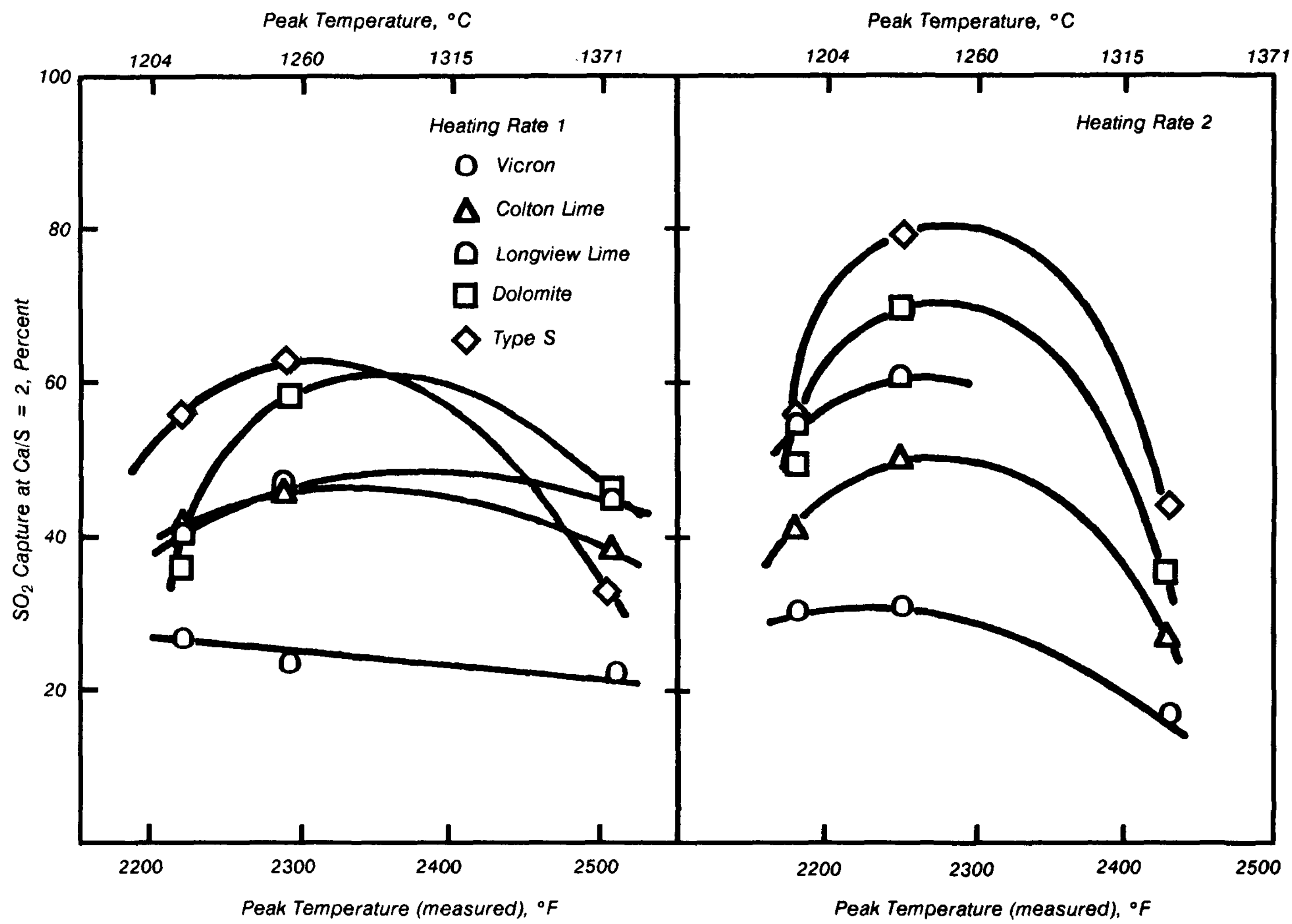

Figure 3. *Effect of peak sorbent temperature on SO_2 capture at different sorbent initial heating rates.*

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The complete report, entitled "Evaluation of Internally Staged Coal Burners and Sorbent Jet Aerodynamics for Combined SO_2/NO_x Control in Utility Boilers: Volume 1. Testing in a 10 Million Btu/Hr Experimental Furnace," (Order No. PB 89-207 955/AS; Cost: $31.00, subject to change) will be available only from:
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