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Project Summary

Testing of Wall-Fired Furnaces to Reduce Emissions of NO$_x$ and SO$_x$

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This research project is one of several programs sponsored by the EPA to investigate and develop simultaneous nitrogen oxide/sulfur oxide (NO$_x$/SO$_x$) emission control using limestone injection in multistage burners (LIMB). The overall technology development programs range from small-scale fundamental investigations to pilot-scale development studies. The overall EPA program includes analysis of boiler design aspects of LIMB technology and a full-scale, wall-fired utility boiler demonstration. One concept of the EPA LIMB program is that there are three basic facets: scientific aspects, pilot-scale studies, and application. LIMB application is likely to be very system-specific, involving analysis of a particular fuel/boiler/burner system, selection of a sorbent and injection method, and consideration of the impact of LIMB on operation of the boiler. Thus, the results of investigations of the fundamental aspects of sulfur capture, pilot-scale studies, and the development of models for the process are essential for the application of LIMB technology.

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 two reports of the same title (see Project Report ordering information at back).

Summary

The research program summarized here provides information into the development effort at several levels. The work reported here involved direct investigations of the role of fuel and sorbent properties and fuel mineral matter interactions. Results of these experimental efforts can be used to clarify the sulfate formation process and to derive guidelines for determining sorbent injection locations. In addition to the experimental work, analytical development work was performed, including the development of a sulfur capture model, and the application of heat transfer models.

The overall goal of the research program was the clarification of means to reduce emissions of NO$_x$ and SO$_x$ from the pulverized-coal, wall-fired combustion systems found in utility boilers. The work was divided into four separate tasks. Task 1 provided detailed information about sorbent and sulfur reactions under conditions of particular interest. Task 2 evaluated the potential of a number of design and sorbent options. Task 3 provided some information on the effect of scale on the performance of systems designed to reduce NO$_x$ and SO$_x$. Task 4 summarized the data produced, providing recommendations on optimum systems and potential operational problems. Tasks 1 and 2, carried out in a 1 million Btu/hr furnace, helped to determine:

- The effect of fuel type and fuel mineral material on sulfur.

- The effect of sorbent type on sulfur capture.

- Detailed temperature and species characteristics of flames which gave significantly different sulfur captures.

- The effect on sulfur capture of operational characteristics such as fuel

injector, burner zone stoichiometry, peak flame temperature, and load.

- The effect of sorbent injection location.
- The effect of LIMB on various furnace operational characteristics such as slagging, fouling, solids loads, size distribution, and fly ash resistivity.

Task 1

Conclusions from Task 1 include:

- A good inverse correlation between added mineral matter alumina (Al_2O_3) content and sulfur capture during gas firing has been observed; the more alumina in the solid, the lower the capture, using either limestone or dolomite

- Sulfur capture for the different coals tested with limestone and dolomite also showed a fairly consistent inverse correlation with the calculated Al_2O_3 content of the ash sorbent mixture (at a Ca/S = 2.0).

- Electron micrographs of sorbent mineral samples show particles composed of a mixture of Al/Si and Ca. The particles are spherical and have been molten at some point in the furnace. The mechanism of mineral deactivation and formation of these spherical particles is not clear and should be the subject of further investigation.

- Electron micrographs of coal/sorbent samples also showed spherical particles composed of calcium and ash minerals such as Al, Si, and Fe.

- Injecting the sorbent downstream from the main flame resulted in improved utilization in coal flames. Experiments with natural gas flames showed that the sorbents had somewhat higher surface areas in the reaction zone when injected downstream. Gas-fired experiments using mineral matter additives showed that mineral material deactivation of the sorbent could be reduced by injecting the sorbent downstream of the main flame.

Task 2

In Task 2, a fairly extensive data base of sulfur capture for various fuel/sorbent pairs was established. Six fuels and five sorbents were tested (not all possible combinations of fuel/sorbent pairs were included).

- The effect of sorbent type on capture with a given fuel was dependent on the firing conditions—including sor-

bent injection location and thermal conditions. The hydrated limes seemed to be more sensitive to thermal conditions and the Vicron limestone least sensitive. The German hydroxide gave better capture than the Colton hydroxide. It was not known why the two had different captures, but the German hydroxide did have a generally smaller particle size distribution than the Colton hydroxide. Dolomite gave the highest capture with all of the fuels tested.

- The effect of fuel type on capture with a given sorbent was also system dependent (injection method, firing characteristics, and thermal conditions).

- In general, sorbent size affected capture only for large particles: at mean sizes less than 10 μm, particle size had little effect on sulfur capture. A comparison of the predicted effect of particle size and the observed effect using various sizes of Vicron limestone was in fairly good agreement.

Task 3

Task 3 was supported by the development of a computer code to model sulfur capture by sorbents and the application of an existing boiler performance/heat transfer code to model facilities at EER, providing a prediction of thermal characteristic.

The sulfation portion of the model is probably adequate for the model application needs except that the predicted effect of SO_2 concentration does not match the available data very well. The sorbent activation portion of the model is the best currently available, but is over-simplified and should be refined as data on the effects of calcination conditions and input sorbent characteristics become available.

The two and three dimensional furnace models are well developed. The application of these is only limited by available data on specific burner/furnace characteristics (e.g., flame shape, size, thermal conductivity, thickness of slag deposits, and emissivity of injected sorbent).

In combining the two models, the furnace heat transfer model was used to predict a temperature/flow map of the furnace. A large number of particles were tracked through the furnace giving a distribution of peak temperature and residence times. The peak temperature distribution was then used to give an average sorbent surface area, and the mean temperature and residence time

were used with this surface area to predict sulfur capture.

This scheme was applied to different size pilot-scale furnaces to predict the effect of scale for a standard condition using the same sorbent, injected with the same fuel (which only affects SO_2 concentration in the current scheme).

The model predictions of capture in different pilot facilities are fairly good at predicting overall ranking of capture in the furnaces. Capture measured in the largest furnace (LS) firing at 100 million Btu/hr ranged from 40 to 53%, depending on the burner and sorbent injection location. (The model predicts slightly higher capture for sorbent injection with the tertiary air in the LS which was also apparent in some of the LS tests.) Captures measured in the medium size furnace (MS) firing at 50 million Btu/hr ranged from 10 to 29%, again depending on burner and sorbent injection location. The highest capture measured in the small furnace (SS) firing at 10 million Btu/hr was 30%, higher than the predicted 23%. The model also does not predict a difference in capture due to sorbent injection location in the SS while experimental results showed a difference as great as from 10 to 30%.

The analytical tools developed are promising, and prediction of some general capture trends is possible; but several gaps in the data and in modeling techniques remain. The available analytical methods do not give sufficient refinement of the processes occurring in the near burner region which, from the experimental results, can have a profound impact sorbent reactivity and sulfur capture. The prediction of sorbent reactivity from measurable properties and projected thermal history is still very inadequate. Insufficient data on the effects of parent stone characteristics (e.g., grain size, composition, and particle size) as well as the effect of various flame-calcination regions (heating rate, peak temperature, quench rate, etc.) on sorbent reactivity currently exist. Further experimental and analytical attention in these areas should provide even more promising results

Task 4

In accordance with Task 4, the complete control effort was summarized. The experiments performed have provided some clarification of the effect of various system parameters on sulfur capture by direct injection of sorbents. Fuel mineral matter has been shown to deactivate the sorbent if the two are injected together in

a high temperature (>2300°F). Downstream sorbent injection (at temperatures of about 2200°F) gave higher captures than injection with the fuel for coal fired tests, because of decreased mineral matter interference and some increase in sorbent surface area. Further experimental work investigating the mechanism of mineral deactivation, the possibility of generating high surface area (highly reactive) sorbents, and the effect of sorbent injection on boiler operating characteristics (especially heat transfer concerns such as flame emissivity) should clarify methods of further reducing emissions.

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