United States Environmental Protection Agency
Research and Development

Air and Energy Engineering Research Laboratory
Research Triangle Park, NC 27711

EPA/600/S7-88/013 Nov. 1988

EPA

Project Summary

Development of Sorbent Injection Criteria for Sulfur Oxides Control from Tangentially Fired Coal Boilers

R. W. Koucky, J. L. Marion, and D. K. Anderson

The report describes a program to develop design criteria for injection of dry sorbents into tangentially fired furnaces for the control of sulfur oxides (SO_X) emissions. The program included aerodynamic cold-flow testing and mathematical modeling of sorbent injection, demonstration testing of SO_X emissions control in a 14.7 MW thermal tangentially fired Boiler Simulation Facility (BSF), and development of recommendations for sorbent injection in a tangentially fired boiler demonstration of the process. The isothermal flow modeling led to development of sorbent injection systems for tangentially fired furnaces which provide high levels of sorbent dispersion. A sorbent dispersion mathematical modeling technique was developed to support flow modeling in identifying and optimizing sorbent injection locations and methods. Sorbent injection tests in the BSF investigated the following variables: sorbent type, injection location, injector tilt, injection velocity, number of injectors, and carrier air flow rate. Sulfur capture efficiency up to 50% was achieved at a Ca/S molar ratio of 2:1 with calcium hydroxide sorbent treated with calcium lignosulfonate. A procedure was developed for specifying sorbent injection locations and methods for a full-scale demonstration of the sorbent injection process in a tangentially fired utility boiler.

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

Furnace sorbent injection is being developed as an approach for sulfur dioxide (SO_2) control for coal-burning utility boilers. The process is attractive for retrofit of existing boilers since the capital equipment requirements are less than for other options such as flue gas desulfurization, and the estimated overall sulfur reduction cost per ton of sulfur removed from flue gas is less than for these options. In the furnace sorbent injection process, sorbent, usually calcium hydroxide [$Ca(OH)_2$] or limestone ($CaCO_3$), is injected above the flame zone and mixes with flue gas containing SO_2. The SO_2 reacts chemically with lime (CaO), formed from the sorbent, to make solid calcium sulfate ($CaSO_4$). The $CaSO_4$ is removed with fly ash in particulate collection equipment.

A significant fraction of the existing boilers in the U.S. that would be candidates for retrofit with sorbent injection technology are tangentially fired utility boilers. Tangential firing introduces special considerations for the design of sorbent injection systems due to the unique aerodynamics in the sorbent mixing region of tangentially fired furnaces. Therefore, a program was established to address the criteria for the location and method of sorbent injection in tangentially fired coal-burning furnaces in order to provide the most effective removal of sulfur oxides.

The program included four tasks:

- Task A - Cold flow modeling of sorbent injection systems.
- Task B - Mathematical modeling of sorbent injection systems, SO_2 capture performance, and furnace thermal performance.
- Task C - Combustion testing of sorbent injection location/injector design combinations in a pilot scale Boiler Simulation Facility (BSF).
- Task D - Sorbent injection system design recommendations for a full-scale tangentially fired boiler demonstration.

Cold Flow Modeling

The cold flow modeling consisted of three screening levels designed to lead to the selection of injector design/location combinations for combustion testing. In the first screening level, flow visualization tests of 16 injector configurations were conducted. Each configuration was evaluated at up to three injector carrier air velocities and three injector nozzle tilt positions. The 11 best injector configurations from the first screening level were evaluated in the second screening level, which consisted of three-dimensional velocity profile measurements and mixing studies using a methane tracer gas measured by a laser absorption spectrophotometer. In the third screening level, the five configurations which demonstrated the best performance in the second level testing were tested over a range of simulated furnace operating conditions using the same techniques utilized during the first two screening levels.

The isothermal flow modeling was performed in the Large Scale Furnace Aerodynamics Test Facility (LSFATF). The facility was a 0.46-scale simulation of the BSF used in Task C. The inflow modeling tests, supported by mathematical modeling, developed several sorbent injection systems which provide high levels of sorbent dispersion for a wide range of sulfation temperature windows and corresponding sorbent injection locations.

Mathematical Modeling

The mathematical modeling effort was divided into three subtasks. One was thermal modeling to provide furnace gas temperature predictions. Thermal modeling was conducted to design the BSF, to select candidate sorbent injector locations for both the isothermal flow studies and the combustion testing at the BSF, and to interpret BSF test results in order to optimize SO_2 capture performance at the BSF. The second modeling subtask was sorbent dispersion modeling which was conducted using a computational fluid dynamics (CFD) code. It was shown that CFD can effectively simulate sorbent mixing in the upper part of a tangentially fired furnace and can be an effective design tool for selecting and optimizing sorbent injector locations and methods. In the third mathematical modeling subtask, a SO_2 capture performance model was developed by application of a proprietary computer code. The model predicts SO_2 capture as a function of furnace geometry, furnace temperature profile and operating conditions, sorbent injection parameters, and the inherent SO_2 capture performance of the sorbent.

Combustion Testing

Combustion testing was performed in a large pilot-scale tangentially fired test furnace to evaluate and optimize sorbent injection concepts developed from isothermal and mathematical modeling studies. Objectives of the combustion testing were to:

1. Evaluate SO_2 capture performance for various injection locations, designs, and operating conditions.
2. Evaluate three hydrated lime sorbents, including a hydrated lime treated with calcium lignosulfonate.
3. Optimize SO_2 capture performance.
4. Refine the sorbent injector design guidelines developed in the cold flow and mathematical modeling tasks.
5. Create a data base for sorbent injection system design guidelines for tangentially fired boilers.

Combustion testing was performed in C-E's new 14.7 MW thermal ($50x10^6$ Btu/hr) BSF. This facility was designed and built by C-E specifically to support the sorbent injection design criteria program. The BSF represents a significant contribution toward EPA's goal of commercializing in-furnace sorbent injection technology for SO_2 control. The facility accurately models the time/temperature history, volumetric heat release rate, heat absorption, and aerodynamic characteristics of a large utility boiler. Both the lower and upper furnaces are modeled so that the region of the boiler where SO_2 capture reactions take place is properly represented.

Tests were performed using an eastern bituminous coal containing 2.7 to 3.2% sulfur. More than 160 tests were performed, including baseline tests, upper furnace temperature characterization tests, and NO_x measurements as well as sorbent injection tests over a range of Ca/S molar ratios, sorbent types, injector tilts, sorbent carrier air velocities, and injector locations. The BSF was found to be representative of a large utility boiler in terms of operation, heat release, gas time/temperature profile, carbon burnout and NO_x/SO_2 emissions. With hydrated lime sorbent treated with calcium lignosulfonate, SO_2 capture efficiency of up to 50% was obtained at a Ca/S molar ratio of 2:1 for selected test conditions.

Design Recommendations

In program Task D, a sorbent injector design procedure for tangentially fired furnaces was developed. This procedure applies the design guidelines, experimental methods, and computational methods developed in the first three tasks of the program. By this step-by-step procedure, injector design features are optimized including injector elevation, peripheral location, size and shape, and operating conditions. This procedure will be applied in selecting the sorbent injector designs for the tangentially fired furnace sorbent injection demonstration program.

Conclusions

This program led to the following major conclusions:

1. Isothermal flow modeling provided sorbent injector designs for tangentially fired furnaces with high levels of sorbent dispersion for a wide range of sulfation temperature windows and corresponding sorbent injection locations. Specific designs were selected and tested in the 14.7 MW thermal BSF.

2. For furnaces in which the beginning of the sulfation temperature window is at or near the arch elevation, injection from a position low in the

front wall provides effective sorbent dispersion.

3. For furnaces in which the beginning of the sulfation temperature window is below the arch, tangential injection from the corners of the unit provides very effective sorbent penetration and dispersion across the furnace plan area.
4. Thermal modeling using proprietary C-E design codes provided significant support to the program for the design of the BSF, selection of injector locations for both the isothermal flow studies and BSF combustion testing, and in interpretation of BSF test results.
5. Computational fluid dynamic (CFD) modeling provides an effective simulation of the flow patterns and mixing in the upper part of tangentially fired furnaces. CFD simulation in combination with cold flow modeling can be used to identify and optimize sorbent injector locations and operating conditions for dry sorbent injection systems for SO_2 control in tangentially fired furnaces.
6. A model was developed to predict SO_2 capture as a function of furnace geometry, furnace temperature profile, operating conditions, sorbent injection parameters, and the inherent SO_2 capture performance of the sorbent by application of a proprietary C-E computer code. The model will be applied in scaling up results of this program for a demonstration of dry sorbent injection technology in a tangentially fired utility boiler.
7. The BSF was found to be representative of a large utility boiler in terms of operation, volumetric heat release, gas time/temperature history, carbon burnout, and NO_x/SO_2 emissions.
8. Three sorbents were tested at the BSF firing an eastern U.S. bituminous coal containing on average 3% sulfur. Sorbent A was untreated Black River hydrated lime, Sorbent B was untreated Marblehead hydrated lime, and Sorbent C was Marblehead hydrated lime treated with calcium lignosulfonate. SO_2 capture varied with sorbent type. Typical SO_2 capture performance results at a calcium/sulfur molar ratio of 2:1 were: Sorbent A, 25-30%; Sorbent B, 30-40%; and Sorbent C, 35-50%.
9. Although most sorbent injection tests were run for a constant 20-minute interval, longer tests showed that SO_2 capture could be increased by 10 or 20% (or 4 to 10 percentage points) by extending sorbent injection to 1 hour. This was due to deposition of reactive sorbent on heat transfer surfaces.
10. Optimum SO_2 capture was obtained by injection into the region where furnace gas temperatures range from 1230 to 1290°C.
11. Injector tilt was demonstrated to be an effective approach for injecting sorbent into the optimum location.

R. W. Koucky, J. L. Marion, and D. K. Anderson are with Combustion Engineering, Inc.. Windsor, CT 06095.
Samuel L. Rakes *is the EPA Project Officer (see below).*
The complete report, entitled "Development of Sorbent Injection Criteria for Sulfur Oxides Control from Tangentially Fired Coal Boilers," (Order No. PB 88-238 357/AS; Cost: $32.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

EPA/600/S7-88/013

0000329 PS

U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBORN STREET
CHICAGO IL 60604