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Project Summary

Evaluation of Emissions and Control Technology for Industrial Stoker Boilers

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This report presents the results of a 3-phase program to evaluate emissions and control technology for industrial stoker boilers. In Phase I, emission characteristics were determined for a variety of coals fired in a 200-kW stoker boiler. It was observed that significant amounts of sulfur were retained in the lignite and western subbituminous coals. Fuel nitrogen conversion to NO was found to be between 10 and 20 percent. In addition, a limestone/coal fuel pellet was developed and found effective in capturing 80 percent of the fuel sulfur. Phase II focused on identifying and evaluating potential control concepts. An 8-MW spreader stoker boiler was used. It was found that improved control of combustion air, that is underfire and overfire air, resulted in lower excess air operation (improved efficiency), reduction in particulate loading, smoke, CO and NO emissions, and had no effect on SO_2 levels. The limestone/coal pellet (Ca/S = 7) was successfully fired achieving 75 percent SO_2 reduction. In Phase III, the limestone/coal fuel pellet was refined. A pellet was produced that had physical properties that could survive an industrial coal-handling system. This pellet with a Ca/S molar ratio of 3½ was fired in the 8-MW boiler achieving sulfur captures of 50 percent. The cost of this pellet would add approximately one dollar per million Btu to the cost of the raw high-sulfur coal.

This Project Summary was developed by EPA's Industrial Environmental 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 coal-fired stoker boiler provides an option for industry to meet its energy needs. This option has not been exercised by a significant number of industries primarily because oil- and gas-fired equipment have been, and still are, more environmentally and economically attractive. However, with the dwindling supplies of oil and gas, the rising costs of these fuels, and increased attention given to coal utilization, industry once again is considering the coal-fired stoker boiler.

In support of our nation's commitments to maintain a clean environment and to utilize coal, EPA funded a research and development program to identify and demonstrate improvements in stoker-coal firing that can provide an incentive for greater industrial use of coal. The overall objectives of this program were to:

- Characterize the spectrum of emissions from industrial coal-fired stoker boilers using several types of coal under various stoker-firing conditions

- Investigate control methods to reduce these emissions
- Determine the effect of these control methods and variations in stoker-boiler operation on the overall performance of the stoker boiler, and
- Assess the environmental impact of new technology on the future acceptability of stoker boilers.

This program was divided into three phases. In Phase I, Alternative Fuels Evaluation, emission characteristics were determined for a variety of coals fired in a 200-kW stoker boiler. Emphasis was focused on identifying coals with low pollutant potential, including both physically and chemically treated coals. In Phase II, Control Technology, potential concepts for control of emissions for full-scale industrial stokers were evaluated. In Phase III, Limestone/Coal Pellet Development, a limestone/coal fuel pellet was developed and evaluated as a viable SO_2 control for industrial stoker boilers.

This report presents the results of the three phases of work. The report is organized into the following three parts corresponding to the three phases of work:

Phase	I.	Alternative Fuels Evaluation
Phase	II.	Control Technology Evaluation
Phase	III.	Limestone/Coal Pellet Development

These parts actually represent separate reports but are included under one cover.

Phase I. Alternative Fuels Evaluation

A 200-kW stoker-boiler facility was used to evaluate characteristics of emissions from combustion of a variety of coals, including coals that could not be conveniently or economically evaluated in larger industrial systems. The stoker was initially operated in an underfeed mode to expand the data base developed in an earlier EPA program[1]. This facility was modified to accommodate a model spreader stoker more typical of an industrial boiler.

Raw coals with low pollution potential and treated coals were evaluated. Because there was only one treated coal available during the time framework of the program, Battelle developed, as part of this program, a limestone/high-sulfur coal fuel pellet.

Results of the Phase I emission characterization were as follows:

NO

For the underfeed stoker, less than 10 percent of the fuel nitrogen was converted to NO, assuming no thermal NO. For the model spreader-stoker, between 10 and 20 percent of the fuel nitrogen was converted to NO.

SO_2

Coals naturally high in calcium and sodium and those treated with these elements retained significant percentages of the sulfur in the ash. For the eastern bituminous coals, with relatively small amounts of calcium and sodium but significant amounts of iron, sulfur retention in the ash was as high as 20 percent. Note that bed temperatures in these laboratory stokers are significantly lower than those measured in an industrial stoker.

CO

CO levels can be controlled by the use of overfire air and were generally less than 100 ppm.

Particulate Loading

Particulate loadings did not correlate consistently with either ash content of the coal or its size prior to feeding. It appears that the friability and inherent moisture content of the coal may affect particulate loading since these properties influence the amount of fines generated.

POM Loadings

POM loadings for continuous operation of the underfeed stoker were significantly less than those reported earlier[1] for intermittent operations.

Particle-Size Distribution

For the model spreader, the average stack particle size ranged between 15 and 30 micrometers.

Treated Coals

No commercially available, chemically treated coals were identified. Treated coals required pelletization for firing i stokers.

The Battelle Hydrothermally Treated (HTT) coal was available for laboratory evaluation. The treatment reduced the fuel sulfur from 2.6 percent to 1.1 percent. Because of the relatively high calcium and sodium residual from the treatment, only 28 percent of the remaining sulfur was emitted as SO_2.

Also, the limestone/coal fuel pellet with a Ca/S molar ratio of 7, reduced SO_2 emissions by over 70 percent. Even at the elevated fuel-bed temperature (> 1100°C), the calcium reacts with the coal sulfur and retains it as a sulfide sulfate as part of the fuel ash.

Phase II. Control Technology Evaluation

Potential control concepts were identified and evaluated in the Battelle 8 MW_{th} (25,000 lb steam/hr) spreader stoker boiler. Control strategies were limited to:

- Use of compliance coals
- Combustion-system operational modifications
- Minor combustion-system design modification
- Use of treated coal (limestone/coal fuel pellet)

Flue-gas clean-up techniques were not considered. Criteria pollutants were used as the basis for evaluation.

The Phase II experiments have demonstrated that emission levels can be reduced by proper control of the stoker operating variables. In addition the limestone/coal pellets have been demonstrated to offer potential for SO_2 control. In summary, the major findings are:

- The limestone/high-sulfur coal pellet showed a sulfur capture of about 75 percent for a Ca/S molar ratio of 7.
- Sulfur capture efficiencies of around 25 percent were noticed with some eastern bituminous coals.

[1]Giammar, R. D., et al., Emissions from Residential and Small Commercial Stoker-Coal-Fired Boilers Under Smokeless Operation. EPA-600/7-76-029, USEPA, Washington, DC 20460, October 1976.

- High excess air rates at low loads result in increased sulfur retention in the bed ash.

- Co and smoke levels can be controlled by providing adequate excess air. CO levels were low for all fuels tested except the limestone/coal pellet.

- Clinker formation may be a limiting factor in determining the minimum excess air rate.

- NO levels increase slightly with increase in excess air.

- Conversion of fuel nitrogen to NO was between 12 to 20 percent, assuming no thermal NO.

- An increase in overfire air/total air flow rate ratio reduced CO and smoke, the latter more significantly. Particulate loadings are also reduced with increased overfire air.

- NO is lower for inactive overfire air jets.

- Clinker formation occurs readily if bed depths become excessive, while the danger of burning the grates exists for operation with very shallow beds. Bed depths around 6.3 to 7.6 cm appear to be optimum for low ash coals.

- POM levels ranged from 13 to 24 $\mu g/Nm^3$. They were somewhat lower than those of the model spreader and only slightly higher than those from a 500 kW packaged boiler firing natural gas and fuel oil.

- A higher excess air rate is required for low-load than for partial- or full-load operation. A greater percentage of overfire air is required at low-load. Low-load smoke can be reduced by a reduction in underfire air, coupled with attentive boiler operation.

- At full-load, fly-ash reinjection increased boiler efficiency by 1.5 percent. However, particulate loadings were reduced by 10 to 25 percent by operating without fly-ash reinjection.

- The high-sulfur Ohio coals had to be fired at higher excess air rates than did the low-sulfur Ohio and Kentucky coals. The high-ash unwashed stoker coal, and high moisture Illinois No. 6 coal could not be fired satisfactorily.

Phase III. Limestone/Coal Pellet Development

The Phase III program focused on refinement of the limestone/coal fuel pellet and evaluation of its suitability as an industrial stoker-boiler fuel. This program consisted of four major tasks.

1. *Pellet Development* aimed at developing a fuel pellet with mechanical strength characteristics that can withstand weathering and the severe stresses of an industrial stoker coal-handling and feeding system, burns at reasonable rates, and captures sufficient sulfur to be competitive with other control strategies. Mechanical strength characteristics were evaluated with standard laboratory tests. Burning characteristics and sulfur capture were determined in a fixed-bed reactor simulating the fuel bed of a spreader stoker.

2. *Process Variables Selection* combining a mathematical model analysis with a series of experimental studies to develop a more comprehensive understanding of the processes that influence the combustion of the fuel pellet and control the capture of sulfur.

3. *Laboratory Evaluations* conducted in both the 200 kW_{th} model-spreader stoker and the 8 MW_{th} Battelle steam plant boiler to evaluate the most promising candidate pellets.

4. *Economic Analysis* aimed at developing pellet process costs.

The major results and conclusions of the four tasks are:

Pellet Development

- A fuel pellet was produced that, according to laboratory tests, has mechanical strength and durability characteristics similar to those of conventional coals.

- Pellets produced by auger extrusion or pellet mill processes had better mechanical strength than those produced by disc pelleting or briquetting.

- Binders that provide some resistance to the weather were identified. However, no binder was identified that provided complete weather proofing.

- The fixed-bed reactor experiments indicated a weak dependency between Ca/S ratio and sulfur capture for Ca/S ratios above 2.

- Calcium oxide is a superior absorbent to limestone, but is not economically competitive with limestone.

- Additives do not appear to enhance sulfur capture.

Process Variables Selection

- The mathematical model predicts an optimum coal size (35-40 mm diameter) for maximum sulfur retention.

- the model indicates a weak dependence on the calcium/sulfur ratio.

- Scanning electron microscopy and x-ray diffusion are powerful tools for the study of solid-state reactions in the pellets. Results indicate that sulfur is retained predominantly as $CaSO_4$.

- Sulfur may react directly with limestone by solid-state processes without involving the formation of SO_2.

Laboratory Evaluations

- Auger-extruded and milled pellets burned better than briquets and disc-agglomerated pellets.

- Sulfur capture of about 65 percent was achieved at Ca/S molar ratios of 3.5.

- Sulfur capture of about 50 percent was achieved in the steam-plant stoker. In comparison to the model spreader, this lower SO_2 capture was attributed to higher temperatures (in excess of 1300°C).

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- Sulfur capture appeared to be weakly dependent on fuel-bed temperature.
- In the Battelle steam power plant, the fuel pellets burned as well as low-sulfur coal.

Economic Analysis

- It is estimated that limestone/coal fuel pellets can be produced for about $15.40/Mg ($14/ton) of pellets above the costs of the high-sulfur coal.

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***John H. Wasser** is the EPA Project Officer (see below).*
The complete report, entitled " Evaluation of Emissions and Control Technology for Industrial Stoker Boilers," (Order No. PB 81-197 873; Cost: $20.00, subject to change) will be available only from:
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