CHARACTERIZING AND REDUCING EMISSIONS FROM OIL-DESIGNED INDUSTRIAL BOILERS RETROFITTED TO FIRE COAL-BASED FUELS

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INTRODUCTION

Penn State is conducting a program to develop coal-based technologies which are applicable to Department of Defense (DOD) facilities. The objectives of the program are to: decrease DOD's dependence on foreign oil and increase its use of domestic coal; promote public and private sector deployment of technologies for utilizing coal-based fuels in oil-designed industrial boilers; and provide a continuing environment for research and development of coal-based technologies for small-scale applications at a time when market considerations in the U.S. are not favorable.

The first phase of the three phase program has been completed and was focused on developing technologies for utilizing micronized coal-water mixtures (MCWMs) and dry, micronized coal (DMC) in fuel oil-designed industrial boilers. These technologies were identified by the U.S. Corps of Engineers, Construction Engineering Research Laboratory (CERL) as being of highest priority to DOD. To evaluate the technical and economic viability of firing coal-based fuels in oil-designed, industrial watertube boilers, proof of concept demonstrations were conducted. Technical aspects of these demonstrations included: coal storage (hoppers for micronized coal; tanks for MCWM) and handling (conveyors, screw feeders, weigh-belt feeders, and pneumatic transport for micronized coal; pumps and piping for MCWM) and integration with the burner; matching various burners with the boiler; combustion and boiler performance; ash deposition, accumulation, and erosion; emissions; and boiler derating.

The second phase of the program, which is currently underway, focuses on characterizing and reducing emissions from oil-designed industrial boilers retrofitted to fire coal-based fuels. Emissions specifically being addressed are SO_2, NO_x, fine particulates, trace elements, and volatile organic compounds (VOCs). Activities include: characterizing air toxic emissions; installing and evaluating a ceramic filter system to remove fine particulate matter; installing and evaluating a sodium bicarbonate injection system to reduce SO_2 emissions; and identifying/developing a NO_x reduction catalyst that is compatible with the typical operating conditions and economic constraints of industrial boilers.

A summary of the results from the first phase of the program (Miller et al., 1995) and the status of the second phase of the program will be presented in this paper.

PHASE I SUMMARY

Phase I activities were focused on developing clean, coal-based combustion technologies for the utilization of both MCWMs and DMC in fuel oil-designed industrial boilers. A specific objective of Phase I was to deliver fully engineered retrofit options for a fuel oil-designed watertube boiler located on a DOD installation to fire either MCWM or DMC. This was achieved through a program consisting of fundamental, pilot-scale, and demonstration-scale activities investigating coal beneficiation and preparation, and MCWM and DMC combustion performance. In addition, detailed engineering designs and an economic analysis were conducted for a boiler located at the Naval Surface Warfare Center, near Crane, Indiana.

Coal Beneficiation and Preparation Studies

Samples of six coals (Taggart seam from Virginia, Lower Kittanning, Upper Freeport and Pittsburgh seams from Pennsylvania, and Indiana VI and Lower Block seams from Indiana) representing a range in the relative processing complexity required to meet sulfur and ash specifications for use in fuel oil-designed boilers were procured. Each of the samples was subjected to extensive characterization by float-sink analysis to determine the required level of cleaning to meet the <5 wt.% ash and <1 wt.% sulfur specification.

Preliminary liberation models were developed in order to establish appropriate (conventional) cleaning strategies which are:

Taggart Seam	Specification can be met without further cleaning;
Lower Block Seam	Specification can be met without further cleaning;
Indiana VII Seam	Gravity separation of -1/4" coal at a density of 1.37 (80% theoretical yield at 5% ash and 0.45% sulfur);
Lower Kittanning Seam	Gravity separation of -1/4" coal at a density of 1.35 (75% theoretical yield at 5% ash and 0.8% sulfur);
Upper Freeport Seam	Gravity separation of -1/4" coal at a density of 1.37 (76% theoretical yield at 5% ash and 0.98% sulfur); and
Pittsburgh Seam	5% ash requirement can be met by gravity separation of -1/4" material at a density of 1.40 (>90% theoretical yield). Grinding to -100 mesh and separation at 1.30 would be necessary to meet the 1% sulfur specification.

MCWM and DMC Combustion Performance Evaluation

The combustion performance evaluation included conducting fundamental studies to determine the effect of the mineral matter on boiler tube erosion and deposition, identify the mechanism of atomizer wear (corrosion or erosion), and computationally model the burner and boiler. In addition, MCWMs and DMC produced from the candidate coals were fired in Penn State's 1,000 and 15,000 lb steam/h watertube boilers. Details of the boilers have been given elsewhere (Kinneman et al., 1988; Miller and Scaroni, 1990; Miller and Scaroni, 1993; and Jennings et al., 1994). The fuels were fired in the 1,000 lb steam/h boiler in order to determine their relative performance, and one of the coals was fired as DMC and MCWM in the 15,000 lb steam/h boiler (which is of similar size to the retrofit candidate at Crane). Accomplishments on this aspect of the program include: modifying and optimizing a full-scale boiler system to fire DMC and MCWM; integrating the coal storage, handling, and micronization systems with the burner (for DMC firing); achieving 98% combustion efficiency (DMC); determining that erosion was not significant in the convective pass; quantifying the extent of deposition during continuous operation; and meeting targeted NO_x emissions of <0.6 lb/MM Btu.

Engineering Design

Two retrofit designs of a DOD boiler at the Crane site to fire either DMC or MCWM were made. Each design package included a fuel preparation system (for the DMC option only; two conceptual MCWM processing circuits were prepared but not engineered), fuel delivery and handling systems, low-NO_x burner, baghouse, forced-draft fan, combustion air preheaters, induced-draft fan, ash silo, stack, and control system. The retrofit designs conform to accepted engineering practices and site requirements. The designs were based on the system in place at Penn State and the information that was learned from operating it. The design packages were appropriate for soliciting bids from engineering/construction firms for completion of the detailed design, construction, and start-up of the candidate DOD boiler.

Cost/Economic Analysis

With respect to direct capital and operating cost considerations, retrofitting boilers at the Crane site to fire DMC and MCWM is not economically viable for a broad range of parameters. Economic viability increases with decreasing capital cost, reduced transportation costs of MCWM, increased performance, and increased demand for MCWM in the local area. This would increase the price differential of the DMC and MCWM with respect to fuel oil and natural gas.

With respect to direct capital and operating costs, new DMC and MCWM-fired boilers at the Crane site are not economically viable for a broad range of parameters. There does not exist a sufficient critical mass of military boilers at this location for this to be a viable option.

Retrofit capital costs, followed by transportation costs, are the major inhibiting factors to the economic viability of MCWM technology at the Crane site. DMC delivered fuel costs are insensitive to fuel demand level. Transportation costs can be improved by developing a lower cost system of transportation dedicated solely to coal. With respect to environmental regulations, DMC and MCWM technologies are economically viable under a broad range of circumstances. Given the small size of industrial boilers, existing pollution control devices will adequately meet current environmental regulations. The regional multiplier effects of DMC and MCWM technologies are not significant for cases of less than 10 and 15 Crane size-equivalent installations, respectively, in a sub-state area. Regional multiplier effects can be significantly enhanced by purchasing more inputs from local vendors, though the sites where this is possible are limited.

PHASE II STATUS

While Phase I focused on the technical aspects of firing coal-based fuels in oil-designed boilers, the primary objective of Phase II is to characterize, in detail, the emissions from coal-fired industrial boilers and to develop strategies to provide for ultra-low emissions. Emissions being addressed are SO_2, NO_x, fine particulate matter (<10 microns), and air toxics (volatile organic compounds and trace elements).

SO_2

In Phase I, SO_2 emissions were minimized through the use of low sulfur coal (<1.0 wt.%). The objective in Phase II is to further reduce SO_2 emissions, which will be accomplished through sodium duct injection. Raytheon Engineers & Constructors examined five commercially viable sorbent injection, SO_2 control technologies for the demonstration boiler and, based on furnace design, thermal profile, ductwork dimensions, and residence time, identified sorbent duct injection as the best candidate.

A sodium dry sorbent duct injection system has been designed to achieve 90% SO_2 removal. The system is under construction and will be operational in September 1996.

NO_x

Demonstration-Scale

In Phase I, NO_x emissions in the demonstration boiler were minimized through the use of low-NO_x burners. It was the intention in Phase II to install a commercially viable system on the demonstration boiler to reduce NO_x emissions even further. Raytheon Engineers & Constructors conducted an NO_x control study for the demonstration boiler and performed a screening analysis of combustion control (low-NO_x burners, flue gas recirculation, over-fire air, and reburning), post-combustion control (selective non-catalytic reduction (SNCR), hot-side selective catalytic reduction (HS SCR), and cold-side catalytic reduction (CS SCR)), and combinations of combustion and post-combustion controls. The screening analysis was conducted in an informal manner since the outcome of the analysis was as expected. Of the candidate process technologies, only SCR was considered capable of satisfying the NO_x reduction requirement of 80-90%. Therefore, the screening analysis consisted primarily of selecting between the cold side and the hot side SCR options. However, because of uncertainty in performance due to the low flue gas temperature with application of HS SCR, and the cost and complexity of the CS SCR, it was decided not to install an NO_x reduction system on the boiler at this time.

Rather than install a CS SCR, activities were directed towards identifying/developing a NO_x reduction catalyst that is compatible with the typical operating conditions and economic constraints of industrial boilers (see NO_x fundamental scale section). A system will be designed and installed on the demonstration boiler in Phase III to test the catalyst(s) identified/developed in Phase II.

Fundamental Scale

The objectives of the fundamental-scale activities are as follows:

- To identify and/or develop a NO_x reduction catalyst that is compatible with the typical operating conditions and the economic constraints of industrial boilers, specifically:
    1. boiler exit temperatures of 550°F (288°C),
    2. O_2 concentrations of 3-5 vol %,
    3. H_2O concentration of 10-20 vol %,
    4. SO_2 concentrations of 500-1,000 ppm,
    5. NO_x concentrations of 100-500 ppm,
    6. No regeneration of sorbent/catalyst required, and
    7. Low maintenance and operating costs;

- To establish the limitations of the candidate NO_x reduction catalyst so that its implementation in pilot and demonstration scale tests will be straightforward, for example, determining the relationship between space velocity and NO_x conversion efficiency for scale-up purposes; and
- To identify maximum allowable transients that the catalyst can be exposed to before losing effectiveness, such as swings in flue gas temperature, and sulfur and unburned hydrocarbon concentrations.

These objectives will be met through the testing of commercially available catalyst technologies, or the development of new catalyst formulations based on current catalyst design experience. The intent is not to develop novel catalysts, but to tailor existing catalyst technology to the specific application of industrial boilers. Tests will be performed in an integral, fixed bed reactor on monolith supported catalysts. A bench-scale flow reactor has been under development to meet the objectives of this subtask and is now ready for experimental testing. The reactor includes computerized temperature control to allow strict monitoring of catalyst temperatures and to allow temperature programmed reaction studies of catalyst behavior. An on-line FTIR spectrometer will provide detailed gas analyses for determination of catalyst conversion efficiency and selectivity.

Fine Particulate Matter (<10 μm)

A ceramic filter is being installed on the demonstration boiler to remove ultrafine particulate and to increase the particulate collection efficiency. It will be adjacent to the existing baghouse and will be capable of filtering the entire flue gas stream. The system is being engineered such that the flue gas stream can be passed either through the existing baghouse or the newly installed ceramic filter. Installation of the new system, which includes the chamber to house the ceramic filters, structural supports, walkways, steps and ladders, ducting, valves, induced draft fan, and associated controls, will be completed in September 1996.

The ceramic filter chamber was designed by Penn State. Comprehensive Design Architects and Engineers (CDAE), of State College, Pennsylvania, designed the structural supports, walkways, steps and ladders, ducting, valves, induced draft fan, and associated controls. The ceramic filters were procured from CeraMem Separations, Inc.. The design criteria of the filters were:

Design face velocity (A/C ratio)	4.00
Volume (acfm)	8,150
Temperature (°F)	400
Grain loading to filters (gr/acf)	3.0
Operating pressure drop (" W.C.)	7-10
Filter area (ft^2)	2,000

The ceramic filtering device will contain 80 filters, 7 inches in diameter and 15 inches long. The current baghouse contains 196 bags, 4.5 inches in diameter and 10 feet long. It is the intent of this portion of the program to demonstrate a smaller, more efficient filtering device for retrofit applications.

Air Toxics (Volatile Organic Compounds and Trace Elements)

The emissions of air toxics from coal-fired industrial boilers will be determined and strategies will be developed/identified to provide for ultra-low emissions.

Volatile Organic Compounds

Particular attention is being given to the formation and/or release of polycyclic organic matter (POM). Specifically, a subgroup of POM called polycyclic aromatic hydrocarbons (PAHs) will be investigated. PAHs include naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[ghi]perylene, dibenz[a,h]anthracene and indeno[1,2,3-cd]pyrene. Little or no detectable amounts of these species have been found in flue gas streams of several utility boilers investigated by the U.S. Department of Energy (Sloss and Smith, 1993). However, with decreasing boiler size, the emissions of these species have been reported to increase due to an increase in the surface area to volume ratio of industrial scale boilers (Chow and Connor, 1993). This produces a decrease in the peak temperature in the boiler. Lower temperatures favor the formation of PAHs. Similar observations have been reported, particularly an increase in the PAHs emissions, in the case of fluidized-bed boilers which operate at 1,470-1,740●F (800-950●C) (Torvela, 1994). Therefore, emphasis will be placed on PAH formation and emissions.

Analytical procedures used for sampling and analysis of the PAHs from the flue gas streams are being identified. An EPA Modified Method 5 sampling train will be utilized in sample collection. Samples from the flue gas stream will be collected prior to and after the baghouse. Appropriate extractions will be performed on the samples and the target compounds will be analyzed using High Resolution Gas Chromatography (HRGC) coupled with either Low or High Resolution Mass Spectrometry (LRMS or HRMS). Testing will begin July 1996.

Trace Elements

Trace element emissions from coal-fired industrial boilers will be characterized. Activities that have been completed include performing a literature search on trace element emissions from coal-fired boilers, specifically from utility-scale boilers, and identifying the necessary sampling equipment and the appropriate analytical techniques.

DOE has completed the first phase of a study, Comprehensive Assessment of Toxic Emissions from Coal-Fired Power Plants, to collect air toxic emissions data from utility coal-fired boilers in response to Title III of the 1990 Clean Air Act Amendments (Weber et al., 1995). Air toxic emissions were measured from eight utility field sites representing various furnace types, fuel types, and backend emissions control systems. The trace elements primarily focused on were arsenic, antimony, barium, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, and selenium. Results showed that, with the exception of lead, coal-fired power plants may be significant contributors to ambient air trace element concentrations. Modified sampling and analysis techniques and refined detection limits will be used in DOE's second phase of testing to verify this.

In the industrial boiler characterization, trace element concentrations and penetration will be determined, with testing focusing on arsenic, mercury, and selenium. The inlet and outlet streams of the baghouse and ceramic filter will be sampled using EPA Methods 5 and 29. The technical issues to be addressed include: 1) evaluating the effect of sootblowing on metals emissions; 2) determining the concentration of trace elements on fly ash particles; 3) determining the distribution of trace elements between solid, liquid, and vapor phases; and 4) comparing trace element emissions between MCWM and DMC. Testing will begin September 1996.

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