Program status: Completed

PROGRAM FACT SHEET

Emissions Characterization & Control During Stationary Combustion

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College of Earth & Mineral Sciences • Penn State University

Goal

The goal was to develop control strategies to achieve ultra-low emissions when firing coal-based fuels in boilers. This was being accomplished through a combination of pilot-scale testing, full-scale demonstrations, detailed characterizations of pollutant formation mechanisms, and computational fluid dynamics (CFD), ash viscosity, and thermodynamic (Gibbs Free Energy) modeling.

Team

A partial list of companies that worked with The Energy Institute in the emissions research and development program include: U.S. Departments of Energy (DOE) and Defense (DOD), Pennsylvania Energy Development Authority, Clean Air Engineering, CeraMem Corporation, CeraMem Separation, Inc., Clean Air Engineering, Corning Incorporated, Englehard Corporation, Foster Wheeler Development Corporation, Ontario Hydro, Raytheon Engineers & Constructors, and the University of North Dakota Energy and Environmental Research Center.

Program Discussion

The stationary combustion emissions program encompassed the formation and control of pollutants from all types of boilers, firing a variety of fuels, and using multiple emissions control options. This included fluidized bed, watertube, firetube, and stoker boilers; fossil and alternative fuels and waste products; wet and dry scrubbers; fabric and ceramic filters; low-NO_x burner technology; selective and non-selective catalytic NO_x reduction; and CO_2 capture and storage.

One major focus in this program area was on emissions control strategies to achieve ultra-low emissions when firing coal-based fuels in industrial-scale boilers. Although industrial-scale boilers were specifically targeted, the technologies developed are applicable to any coal-fired boiler facility because the scale of the Penn State system is sufficient to represent utility boilers. The emissions addressed include SO_2, NO_x, fine particulate matter ($PM_{2.5}$), and inorganic and organic air toxics. In addition to achieving ultra-low targets of SO_2, NO_x and particulate matter, a detailed characterization of air toxics, specifically mercury, from coal-fired industrial boilers was conducted to assist DOE in identifying control strategies.

Background

DOE and DOD recognized, since the late 1980's, the importance of positioning the U.S. for the use of coal and alternative fuels in industrial boilers designed for natural gas and fuel oil. Penn State has been working at developing and integrating technologies to fire coal-based fuels as well as alternative fuels in industrial boilers for DOE since 1989. This effort was later intensified in 1992 when DOD established a National Center of Excellence for Coal Utilization at Penn State. The charge to the Center was to develop clean coal-based technologies to: decrease DOD's dependence on foreign oil and increase its use of coal; promote public and private sector deployment of technologies for utilizing coal-based fuels in oil-designed combustion equipment; and provide a continuing environment for research and development of coal-based technologies for small-scale applications at a time when market conditions in the U.S. were not favorable. Combined with significant industry sponsorship, the program was conducted for more than a decade, and emphasized the development of near-zero emissions technologies for coal-fired boilers.

Demonstration Boiler Site with Baghouse, Ceramic Filter, and Duct Sorbent Injection Systems

The final program activities expanded upon emissions reduction strategies through the use of deeply-cleaned coals as a means for reducing air toxics, lowering fine particulate matter and mercury emissions even further by using ceramic filters, in lieu of fabric filters, and performing a preliminary CO_2 removal/ sequestration study through bench-scale investigations and pilot-scale verifications.

Results

A brief synopsis of the various activities is contained in this section. This review is not all encompassing, but rather it provides a summary of the types of work that are performed.

SO_2

Control of SO_2 emissions was evaluated through the use of circulating fluidized bed combustors and forced oxidation wet flue gas desulfurization scrubbers, both of which are presented on separate fact sheets, and dry sorbent duct injection (DSI). DSI has been demonstrated for use in industrial boilers with greater than 96% SO_2 capture (with resulting SO_2 emissions of 0.04 lb/ million Btu) demonstrated.

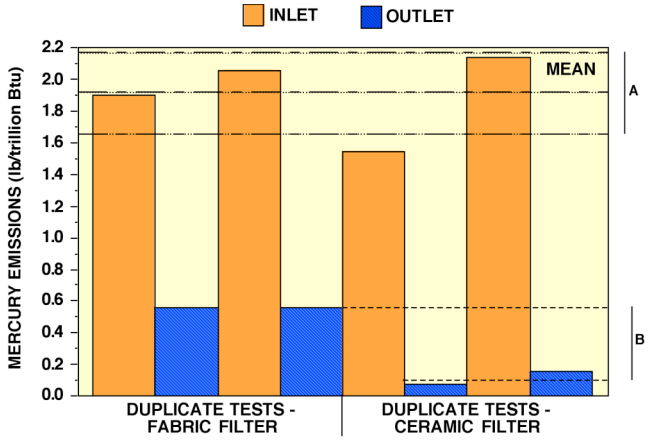
NO_x

Extensive studies on NO_x formation, reduction, and control have been conducted through fundamental CFD modeling, kinetic studies on nitrogen and volatile matter evolution and NO_x production, use of low-NO_x burners, testing of a low-temperature selective catalytic reduction technique, and evaluations of reburn and cofiring technologies.

Examples of reductions in NO_x includes the following: up to 50% reduction has been demonstrated using commercial low-NO_x burners in the demonstration boiler; up to 90% reduction is achievable using low-temperature (i.e., typical baghouse temperatures) selective catalytic reduction in laboratory scale tests, although selectivity to N_2 is not ideal and the catalyst produces some N_2O; up to 10% reduction has been observed during sodium bicarbonate injection for SO_2 control; and up to 30% reduction was obtained when cofiring coal-water slurry fuel and pulverized coal in a Pennsylvania utility boiler as compared to firing only pulverized coal.

Fine Particulate Matter and Mercury Emissions from Ceramic Filters

Penn State conducted a program in which fine particulate matter ($PM_{2.5}$) and inorganic hazardous air pollutants (IHAPs) were characterized when firing coal-based fuels. Details of the IHAPs work and sampling methodology that have been developed are contained on a separate fact sheet. In the fine particulate matter program, dead-ended honeycomb ceramic filters for fine particulate and mercury removal from industrial boilers have been evaluated. A ceramic membrane filter system was designed and installed on Penn State's demonstration boiler to determine fine particulate removal capabilities and to compare its performance with that of a fabric filter baghouse fitted with high-performance bags. Specifically: the system was operated for more than 2,000 hours; the filters are regenerable, although the pressure drop across them is higher than planned; particulate collection efficiencies are slightly higher across the ceramic filters than across the fabric filters in the pulse-jet baghouse; stack particulate emissions are below DOE's Low Emissions Boiler System target (0.01 lb particulate/million Btu) and approach DOE's High Performance Power System target (0.003 lb particulate/million Btu); and mercury emissions were significantly lower from the ceramic membrane filters than from the fabric filters.



Mercury Reduction in Baghouse vs Ceramic Filter
(A. One standard deviation inlet concentration
B. 79% reduction in Hg emissions)

CO_2

Research and development into CO_2 capture from flue gas and its sequestration are currently underway and are presented on separate fact sheets.

Key Contact

Bruce Miller, bgm3@psu.edu, (814) 865-3093

Key Publications

Miller, B.G., S. Falcone Miller, S.V. Pisupati, C. Song, R.S. Wasco, R.T. Wincek, X. Xu, A.W. Scaroni, R. Hogg, S. Chander, M.T. Ityokumbul, M.S. Klima, P.T. Luckie, A. Rose, R.L. Gordon, J. Lazo, and A.M. Schaal, "The Development of Coal-based Technologies for Department of Defense Facilities; Phase III Final Report, Prepared for the U.S. Department of Energy Federal Energy Technology Center, Pittsburgh, Pennsylvania, Phase III Final Report, January 30, 2004, 665 pages; Phase II Final Report, July 31, 2000, 784 pages; Phase I Final Report, January 31, 1997, 590 pages; DE-FC22-92PC92162.

Miller, B. G., S. Falcone Miller, R. T. Wincek, and A. W. Scaroni, "A Demonstration of Fine Particulate and Mercury Removal in a Coal-Fired Industrial Boiler Using Ceramic Membrane Filters and Conventional Fabric Filters," *EPRI-DOE-EPA Combined Utility Air Pollutant Symposium "The Mega Symposium",* Atlanta, Georgia, August 16-20, 1999. (pdf)

Miller, B. G., S. Falcone Miller, J. L. Morrison, and A. W. Scaroni, "Cofiring Coal-Water Slurry Fuel with Pulverized Coal as a NO_x Reduction Strategy," *14th Annual Internat. Pittsburgh Coal Conference*, Taiyuan, Shanxi, Province, People's Republic of China, September 23-27, 1997. (pdf)