Program status: Completed

P R O G R A M   F A C T   S H E E T

Penn State's Coal-Water Slurry Fuel Program

The Energy Institute • www.energy.psu.edu
College of Earth & Mineral Sciences • Penn State University

Goal

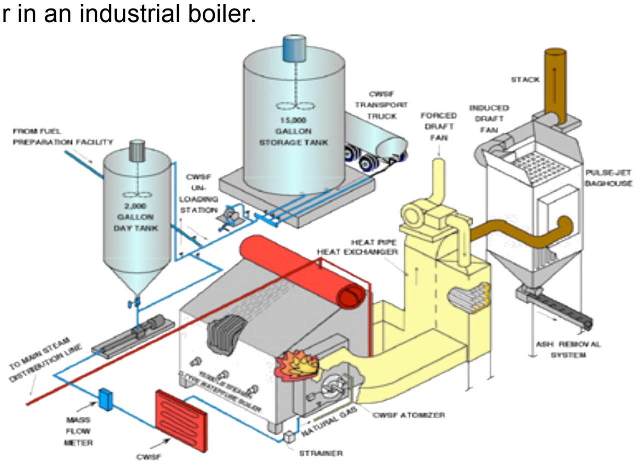
The goal of Penn State's coal-water slurry program (CWSF) was to develop CWSF preparation and combustion expertise that was available for government and industry to tap into and to assist in the commercialization of coal and CWSF cofiring and CWSF reburning technologies. The focus was on establishing acceptable CWSF formulation and preparation procedures and obtaining satisfactory combustion performance in fuel oil-designed industrial boilers, and during cofiring with pulverized coal in utility boilers.

Team

A partial list of participants in Penn State's CWSF program included: The Commonwealth of Pennsylvania, The Energy Institute, U.S. Departments of Energy (DOE) and Defense (DOD), Pennsylvania Energy Development Authority (PEDA), Electric Power Research Institute, Reliant Energy (formerly Penelec), Homer City Coal Processing Company, Tennessee Valley Authority, CQ Inc., Allis Minerals Systems, AMAX Research & Development, Washington Energy Processing Company, and CWF Italia.

Program Discussion

CWSF research and development were an integral part of The Energy Institute's activities for nearly 20 years since the early 1980's. Fundamental, pilot, and demonstration-scale activities provided a detailed understanding of the chemical and physical phenomena involved in CWSF rheology and stability, atomization and combustion, mineral matter transformations, atomizer tip and boiler tube erosion, ash settling and deposition, boiler derating, and emissions. The scale at which research was conducted in this program ranged from single droplet combustion to tons of CWSF per hour in an industrial boiler.



CWSF Demonstration Boiler

Background

In the CWSF program, Penn State assessed the viability of future oil-to-CWSF boiler retrofits, starting with determining the status of commercially-available CWSF burners and atomizers in the U.S. as the first step in retrofitting two package, oil-designed boilers at Penn State. This was followed by the conversion of the boilers, 1,000 and 15,000 lb steam/h, from oil to CWSF and subsequent multiyear test program. During this test program, a demonstration-scale CWSF preparation circuit capable of producing CWSF from coal or filter cake was developed and constructed.

Penn State was actively involved in the development of ***two types, highly loaded and low solids, of CWSFs***. Initially, efforts were focused on high-solids CWSFs, which contain 60 to 70% coal, and are tailored for fuel oil displacement in oil-fired boilers. This CWSF is mostly of pre-1990 interest and is costly to prepare. Penn State worked with many coals from around the U.S. and the world on this fuel type and developed an operating manual with recommendations for preparing, pumping, storing, atomizing, and combusting CWSF. At this time, there is interest overseas in using this fuel type, however, there is little or no interest in use of this CWSF in the U.S. because of its cost to prepare.

Penn State is a leader in characterizing and producing low-solids CWSFs. This is a fuel that is much less costly to prepare, is viewed as a cofire fuel for coal-fired boilers for reducing NO_x emissions, and is prepared from existing wet coal fines using high-intensity mixing circuits. The driving forces for using these coal fines are that there are vast quantities of waste coal fines, coal-fired utilities view these as a potentially inexpensive fuel source as well as a relatively inexpensive means for reducing NO_x emissions, and coal producers view fines as a potential revenue source.

Penn State started working with the low-solids CWSFs in 1990 with Penelec (now known as Reliant Energy) to address a fine coal handling problem. In that program, combustion studies were performed to demonstrate the viability of utilizing this stream in slurry form. This was followed with joint programs with Penelec and PEDA in which Penn State characterized impoundments within a certain radius of Penelec's Homer City/Seward Stations for use as a cofire fuel for reducing NO_x emissions. Penn State was requested to be part of every utility-scale cofiring or reburning demonstration in the U.S. In addition to participating in several demonstrations at Pennsylvania boilers, Penn State has characterized impoundments and/or participated in demonstrations in Alabama, Tennessee, Illinois, and Kentucky.

Results

Formulation and Preparation of CWSF

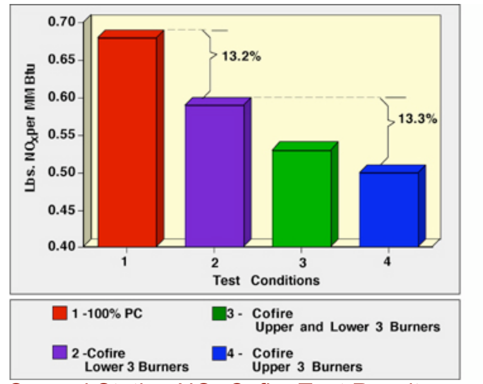
CWSF formulation and preparation progressed from bench-scale (pound quantities) to pilot-scale (tons/h) production levels. Highly loaded and stable CWSFs have been prepared from deeply-cleaned coals for fuel oil substitution in industrial boilers. Low solids CWSFs have been prepared from fines from active cleaning plants and abandoned impoundments to cofire with pulverized coal in utility boilers. Formulation procedures have been documented, and potential problems and solutions in the preparation and handling of CWSF have been identified. It has been found that oxidation of impounded coal fines had not occurred to an extent that affected CWSF formulation, and the same formulation, preparation, and utilization procedures could be used as for fines from active cleaning plants.

Fundamental Studies

Early studies focused on increasing the combustion rate of CWSFs so that acceptable burnout could be achieved in the available residence time in retrofitted boilers. Oxygen enrichment of combustion air was found to improve the combustion efficiency by increasing the flame temperature and hence the char combustion rate. NO_x emissions increased, however, while SO_2 emissions were relatively unaffected. Secondary atomization of CWSF droplets due to explosive boiling required a heat flux in excess of that associated with conventional boilers, regardless of the additives used in the formulation. Combustion enhancement by imposing a high-intensity acoustic field to generate large and rapidly fluctuating gas velocities (relative to the CWSF droplets) was attributed to increased convective heat and mass transfer rates. Atomization quality, mineral matter size, and occurrence of mineral matter in coal particles affected the resulting ash particle size. An erosion-corrosion model, based on accelerated erosion tests, indicated that significant boiler tube erosion does not occur if the flue gas velocity in the convective section is below the value required to keep the erosion in the oxide scale regime.

Retrofitting Industrial Boilers

Penn State retrofitted two package boilers to assess the viability of utilizing CWSF in oil-designed boilers. The boilers were used to: determine the effect of boiler operating parameters (i.e., atomization quality, fuel particle size, level of combustion air preheat temperature) on combustion performance; automate the firing system, particularly with respect to start up and shutdown procedures but also to optimize boiler performance; evaluate fuels; determine the level of boiler derating (< 15%); determine the maximum ash level (~5 wt.%) tolerable; determine the ideal coal particle size distribution (D(v,0.5) = ~18 μm); and evaluate emissions such as SO_2, NO_x, and trace elements as well as the reduction of trace element emissions through fine coal cleaning.



Seward Station NO_x Cofire Test Results

The system and operating knowledge (e.g., level of combustion air and CWSF temperature, proper flow meters, gauges, and piping geometries, mixer types, and tank and baffle dimensions and geometries) gained from the demonstration boiler was used to design the retrofit of an oil-designed boiler located on a military base to fire CWSF.

Cofiring CWSF and Pulverized Coal in Utility Boilers

Interest in cofiring CWSF and pulverized coal was mainly due to its potential as a low cost NO_x control technique. CWSFs produced from coal cleaning plant filter cake and from impounded coal fines were handled and cofired with pulverized coal in an utility boiler. Cofiring reduced NO_x emissions by nearly 30% by the CWSF acting as a reburn fuel. The burner configuration increased the concentration, and changed the spatial distribution, of hydrocarbon radicals within the combustor, with the net effect of reburning to N_2 the NO_x produced in the pulverized coal flames.

Key Contact

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

Key Publications

Morrison, J. L., B. G. Miller, and A. W. Scaroni, "*Determining Coal Slurryability: A UCIG/Penn State Initiative*," Prepared for the Electric Power Research Institute's Upgraded Coal Interest Group, January 1998, WO3852-06, 250 pages.

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 International Pittsburgh Coal Conference*, Taiyuan, Shanxi, Province, People's Republic of China, September 23-27, 1997. (pdf)

Falcone Miller, S., B. G. Miller, A. W. Scaroni, S. A. Britton, D. Clark, W. P. Kinneman, S. V. Pisupati, R. Poe, R. S. Wasco, and R. T. Wincek, "Coal-Water Slurry Fuel Combustion Program Final Report," Prepared for Pennsylvania Electric Company, Johnstown, Pennsylvania, June 1993, Agreement #219549, 98 pages.

Falcone Miller, S., H. H. Schobert, "*The Effect of Mineral Matter Particle Size on Ash Particle Size Distribution During Pilot-Scale Combustion of Pulverized Coal and Coal-Water Slurry Fuels*," Energy and Fuels, 7, pp. 532-541, 1993. (pdf)

Miller, B. G., and A.W. Scaroni, "Superclean Coal-Water Slurry Combustion Testing in an Oil-Fired Boiler," Eight Annual Coal Preparation, Utilization and Environmental Control Contractors Conference, U.S. Department of Energy, 27-34, 1992.

This publication is available in alternative media on request.
Penn State is committed to affirmative action, equal opportunity, and the diversity of its workforce. (July 2005) U. Ed. EMS 06-08