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Particulate Control Device (PCD) Testing at the Power Systems Development Facility, Wilsonville, Alabama

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PARTICULATE CONTROL DEVICE (PCD) TESTING AT THE POWER SYSTEMS DEVELOPMENT FACILITY, WILSONVILLE, ALABAMA

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INTRODUCTION

One of the U.S. Department of Energy's (DOE's) objectives overseen by the Morgantown Energy Technology Center (METC) is to test systems and components for advanced coal-based power generation systems, including integrated gasification combined cycle (IGCC), pressurized fluidized-bed combustion (PFBC), and integrated gasification/fuel cell (IGFC) systems. [1]

Stringent particulate requirements for fuel gas for both combustion turbines and fuel cells that are integral to these systems. Particulates erode and chemically attack the blade surfaces in turbines, and cause blinding of the electrodes in fuel cells. Filtration of the hot, high-pressure, gasified coal is required to protect these units. Filtration can be accomplished by first cooling the gas, but the system efficiency is reduced. High-temperature, high-pressure, particulate control devices (PCDs) need to be developed to achieve high efficiency and to extend the lifetime of downstream components to acceptable levels. Demonstration of practical high-temperature PCDs is crucial to the evolution of advanced, high-efficiency, coal-based power generation systems.

The intent at the Power Systems Development Facility (PSDF) is to establish a flexible test facility that can be used to (1) develop advanced power system components, such as high-temperature, high-pressure PCDs; (2) evaluate advanced power system configurations; and (3) assess the integration and control issues of these advanced power systems.

FACILITY DESCRIPTION

The PSDF is located 40 miles southeast of Birmingham, Alabama, at the Southern Company's Clean Coal Research Center in Wilsonville, Alabama. The facility design reflects the research and development needs of advanced power systems identified by DOE and the Electric Power Research Institute (EPRI).

The PSDF project team is led by Southern Company Services (SCS) and is composed of M. W. Kellogg, Foster Wheeler, Westinghouse, Allison, Southern Research Institute, and several developers of PCDs, including Westinghouse, Industrial Filter and Pump, and Combustion Power Corporation. The involvement of these diverse private sector organizations will ensure that the duration, scale, and results of the PSDF test program are sufficient to gain private sector acceptance.

The PSDF combines five pilot-scale test facilities at a single site, thus reducing overall capital and operating costs compared to individual stand-alone facilities. The combination of these pilot-scale facilities in a new 60 x 100 foot structure and shared resources common to different modules, such as coal preparation, are estimated to save a nominal $32 million over the cost of separate facilities.

The five major technologies at the PSDF will be an advanced pressurized fluidized-bed combustion (APFBC) system, a transport reactor gasifier/combustor, four particulate control devices, a topping combustor/combustion turbine system, and a fuel cell. Gas streams exist on the two gas-producing modules for the four separate PCD technologies, and three can be tested simultaneously at the PSDF.

The PSDF will also support the DOE Clean Coal Program.

Short-term parametric tests will be conducted using the transport reactor. M.W. Kellogg's transport reactor technology was selected due because it has the flexibility to produce particulates under either pressurized combustion (oxidizing) or gasification (reducing) conditions. The reactor will be used for parametric testing of PCDs over a wide range of operating temperatures, gas velocities, and particulate loadings.[2] The transport reactor can vary the particle size distribution, solids loading, and other characteristics of the particulate in the gas stream. The transport reactor is sized to process a nominal 2 tons/hr (1,814 kg/hr) of coal to deliver 1,000 actual cubic feet per minute (acfm) (.472 actual m^3/s) of particulate-laden gas to the PCD inlet over a temperature range of 1,000-1,800 °F (538 to 982 °C) at 184-283 pounds force per square inch absolute (psia) (1,269-1,951 kPa). Two PCDs will be tested on the transport reactor at alternate times.

A fuel cell will be integrated with the transport gasifier. A 20-kilowatt molten carbonate fuel cell will be tested initially using EPRI's fuel cell test skid. The purpose of the initial tests will be to measure the effects of coal-derived gas impurities resulting from a hot-gas cleanup system on fuel cells. Later, using a larger fuel cell, testing will begin to address integration issues and overall plant performance for IGFC systems. Other types of fuel cells can be tested at the PSDF.

The APFBC system consists of Foster Wheeler's technology for second generation PFBC.[3] The advanced PFBC system consists of a carbonizer that operates at 170 psia (1,172 kPa) and 1,600 to 1,800 °F (871-982 °C) to generate 1,500-1,700 acfm (.708 to .802 actual m^3/s) of fuel gas with a low-British thermal unit (Btu) content. The unreacted char from the carbonizer is fed to a circulating, pressurized, fluidized-bed combustor (CPFBC) operating at 150 psia (1,034 kPa) and 1,600 °F (871 °C), generating 6,200 acfm (2.93 actual m^3/s) of combustion gas. The coal feed rate to the carbonizer will be 2.75 tons/hr (2,495 kg/hr). A Ca/S molar ratio of 1.75 is required to capture 90 percent of the sulfur in the carbonizer/CPFBC. Ash from the CPFBC will pass through a fluid-bed heat exchanger.

The gases exiting from the carbonizer and the CPFBC will each be filtered hot in separate PCDs to remove particulates and passed through alkali-getter vessels to remove alkali prior to entering a topping combustor. The topping combustor will burn fuel gas from the carbonizer using the flue gas from the CPFBC as the oxidant to raise the inlet temperature of the gas turbine to 2,350 °F, consistent with turbine inlet temperatures offered on advanced, commercial, high-efficiency turbines.[4] This will raise the net plant efficiency of advanced PFBC systems to 45 percent, while maintaining low levels of nitrogen oxides.

To withstand the expected severe conditions in the topping combustor application, the multi-annular swirl burner developed by Westinghouse has been chosen. At the PSDF, however, the topping combustor flue gas will be cooled to 1,970 °F (1,077 °C) in order to meet the temperature limitation of the small, standard gas turbine (Allison Model 501-KM) that will be used to power both the air compressor and an electric generator. This small generator will produce a nominal 4 megawatts of electric power.

PARTICULATE CONTROL DEVICES (PCD's)

Four PCDs will be tested at the PSDF at the temperatures, pressures, and other gas conditions characteristic of a number of gasifiers and PFBCs.[5] PCDs from three developers have been selected for initial testing at the PSDF. These PCDs were selected in response to two requests for proposals (RFPs), an RFP for three smaller PCDs and an RFP for a larger PCD. The three smaller PCDs that will clean gases from both the Foster Wheeler carbonizer and Kellogg's transport reactor are the same size, to allow them to be moved between systems. The larger PCD will be tested on the combustion gases from the CPFBC.

The critical issues to be studied include integrating the PCDs into the advanced power systems, on-line cleaning, chemical and thermal degradation of components, fatigue and other modes of physical failure, blinding, collection efficiency as a function of particle size, and scale-up issues.

The four sets of operating conditions are shown in Table 1.

TABLE 1

PCD Operating Conditions

	Transport Reactor Combustion	Transport Reactor Gasification	PFBC Carbonizer	PFBC Fluidized Bed Combustor
Temperature	1000-1600 F (538-871 C)	1000-1800 F (538-982 C)	1600-1800 F (871-982 C)	1600 F (871 C)
Pressure	200-300 psia (1379-2068 kPa)	200-300 psia (1379-2068 kPa)	170 psia (1172 kPa)	150 psia (1034 kPa)
Gas Flow Rate	1000 acfm (.472 m3/s)	1000 acfm (.472 m3/s)	894-980 acfm (.421-.462 m3/s)	6200 acfm (2.93 m3/s)
Particle Loading	4000-16000 ppmw	4000-16000 ppmw	11000 ppmw	15000 ppmw

Westinghouse Filter

Westinghouse will use a refractory-lined, coded, pressure vessel for one of the smaller filters that can be fitted with ceramic candles, cross-flow filters, CeraMem ceramic filters, or 3M ceramic bag filters. Individual filter elements will be attached to a common plenum and discharge pipe to form clusters. Clusters of filters will be supported from a common high-alloy, uncooled, tubesheet. Each plenum of the filter will be cleaned from a single pulse nozzle. The number and size of the filters required will vary, depending on the filter type.

Industrial Filter and Pump Fibrosic Candle Filter

A small filter will be provided by Industrial Filter and Pump (IF&P). IF&P filters are ceramic candles made of low-density aluminosilicate fiber/silica and alumina binder and have densified monolithic end caps and flanges. The tubesheet is made of the same densified material. The 60-inch (152.4 cm) diameter, refractory-lined filter vessel will contain 78 candles arranged in six groups of 13 each for pulse cleaning. Individual jet pulse nozzles are provided to each candle. An Enhancer™, consisting of an orifice-type device at the outlet of the candle, increases the pulse intensity and also serves as a fail-safe plug in case of a candle failure.[6]

Combustion Power Company (CPC) Granular-Bed Filter

The CPC granular-bed filter is the same size as the smaller filters, but will not be tested initially on the PFB. Gas is introduced into the center of a downward moving bed of granules in this filter. The granules are 6 mm spheres that are composed of aluminum oxide and mullite. The granules serve as the filter medium that removes the particles from the gas. The gas reverses direction and moves counter-current to the direction of the filter medium and leaves the pressure vessel. Clean medium is constantly introduced at the top of the vessel. The particulate-containing medium is removed from the bottom of the filter vessel and is pneumatically conveyed and cleaned in a lift pipe. At the top of the lift pipe, the particulate and clean medium are separated in a disengagement vessel and the clean medium is returned to the filter vessel. The transport gas and dust are cooled in a regenerative heat exchanger and the dust is removed in a baghouse. The transport gas is cooled in a water-cooled heat exchanger and a mist eliminator. Then, a boost blower is used to overcome the pressure drop in the system and the gas is reheated in the regenerative heat exchanger, and recycled to the lift pipe.

Westinghouse Ceramic Candle Filter

A larger Westinghouse filter will be tested on the PFBC combustor. This filter will contain six clusters of ceramic candles in a 10.2 ft (3.11 m) outside diameter, refractory-lined pressure vessel. Each array of filters is attached to a common plenum and discharge pipe and is cleaned by a single pulse nozzle. Several arrays of individual candle filter elements are assembled into a cluster, and the clusters are arranged vertically in the filter vessel. The cluster concept allows replacement of individual filters and provides a modular approach to scaleup.

CURRENT STATUS/SCHEDULE

All of the initial technologies have been selected and contracts have been signed. Environmental approvals for the PSDF were received in August 1993. Site preparation was completed in December 1993. Detailed design was completed in mid-1995. Construction began in November 1995 and is nearing completion. Startup will occur in steps as construction is completed, beginning with the transport reactor in November 1995 and continuing during the next year. The fuel cell will be added in 1997.

A detailed test plan is being developed for the first operating phase. It is expected that additional operating phases will be funded, with the addition and/or substitution of other equipment and processes.

SUMMARY

The PSDF design incorporates advanced power system equipment into integrated process paths. The size of the PSDF allows key component and system integration issues to be addressed at a reasonable engineering scale. Besides individual components testing, this design scheme allows testing and demonstration of completely integrated, advanced, coal-based power generating systems. PCDs and components may be tested under long-term, realistic IGCC and advanced PFBC conditions.

Such testing of components and systems under long-term, realistic conditions are critical to the development of cleaner, more efficient, coal-fired power generating systems. The PSDF will play an important role in supporting scale-up to demonstration plant size. These tests will have a significant impact on the design and cost of demonstration plants for the future development of new technology.

The result of this project will be a reduction or stabilization in the cost of electricity and a reduction in environmental emissions for new coal-based power plants.

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