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The Morgantown Energy Technology Center's Particulate Cleanup Program

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By
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Abstract

The development of integrated gasification combined cycle (IGCC) and pressurized fluidized-bed combustion (PFBC) power systems has made it possible to use coal while still protecting the environment. Such power systems significantly reduce the pollutants associated with coal-fired plants built before the 1970s. This superior environmental performance and related high system efficiency is possible, in part, because particulate gas-stream cleanup is conducted at high-temperature and high-pressure process conditions.

The demonstration and eventual commercialization of highly efficient IGCC and PFBC power systems are supported through the U.S. Department of Energy (DOE) Clean Coal Technology (CCT) Demonstration Program. A main objective of the Particulate Cleanup Program at the Morgantown Energy Technology Center (METC) is to ensure the success of the CCT demonstration projects.

METC's Particulate Cleanup Program supports research, development, and demonstration in three areas: (1) filter-system development, (2) barrier-filter component development, and (3) ash and char characterization. The support is through contracted research, cooperative agreements, Cooperative Research And Development Agreements (CRADAs), and METC's own in-house research. This paper describes METC's Particulate Cleanup Program.

Introduction

The availability of reliable, low-cost electricity is a cornerstone of U.S competition in the world market. DOE projects the total consumption of electricity in the U.S. to rise from 2.7 trillion kilowatt-hours in 1990 to 3.5 trillion in 2010. Although energy sources are diversifying, 90 percent of our energy is still produced from fossil fuels. Coal is our most abundant fossil fuel resource and the source of 56 percent of our electricity. It has been the fuel of choice because of its availability and low cost. A new generation of high efficiency power systems has made it possible to continue the use of coal while still protecting the environment. Such power systems virtually eliminate the pollutants associated with coal-fired plants built before the 1970s.

Integrated gasification combined cycle (IGCC) and pressurized fluidized-bed combustion (PFBC) are among this new generation of advanced coal-fired power systems. In IGCC and PFBC systems, coal-derived gases are cleaned at elevated pressures and temperatures, which makes them compatible with gas-turbine power generation systems.

METC's Particulate Cleanup Program was designed to help ensure the success of the DOE CCT Demonstration projects, which are the demonstration showcase for IGCC and PFBC power systems.

METC's Particulate Cleanup Program

The main objective of METC's Particulate Cleanup Program is to help ensure the success of the CCT Demonstration projects. To achieve this objective, a program of research, development and demonstration (RD&D) on high-temperature and high-pressure particulate removal technology was implemented. This RD&D helps reduce the technical risks associated with the large-scale demonstrations projects.

Program Approach

METC's Particulate Cleanup Program supports METC's PFBC and IGCC Product Plans by ensuring the success of those CCT Demonstration projects using IGCC or PFBC technology through long-term testing of barrier filter systems under PFBC and IGCC conditions. METC used planning tools [1] to focus RD&D resources into technical areas that support the program objective. The resulting program addresses three technical areas: (1) filter-system development, (2) barrier-filter component development, and (3) ash and char characterization.

Filter-System Development

The METC Particulate Cleanup Program has supported the testing of filter-systems and their related filter-system components. These systems include barrier and granular-bed type filters, which have been demonstrated to meet performance requirements and have attracted the greatest commercial interest [2]. At least two manufacturers are developing each of these two systems through METC's particulate Cleanup Program.

Granular Bed Filters. Granular-bed filter systems are being developed by Combustion Power Company (CPC), Inc. and the Westinghouse Science & Technology Center. Both systems utilize a slowly moving bed of granular material to capture particulates. In the CPC system, the dirty gas flows counter-current to the bed of granular material, in thee Westinghouse system the dirty gas flow is co-current to the bed material. Both systems will require ancillary equipment to convey granular bed material to and from the system. Both granular-bed systems should achieve the required particulate capture-efficiency and may offer other contaminent control options. The CPC granular bed filter system has been selected for pilot-scale testing at the Power Systems Development Facility (PSDF).

Barrier Filter-Systems. Three barrier filter system suppliers are being supported directly or indirectly through METC's efforts to develop technically low-risk and commercially competitive systems. These suppliers include Westinghouse Science & Technology Center, Industrial Filter & Pump Mfg. Inc., and Pall Advanced Separations Systems.

The Westinghouse Science & Technology Center's (Pittsburgh, PA) Advanced Particle Filter (APF) system has barrier filters (typically, candle elements) that are attached to plenums; the plenums are suspended vertically to form clusters [3]. The internal structure of the APF is adaptable to other barrier filter elements. The APF has been tested extensively at pilot-scale [4] and demonstration-scale [5], totaling over 8,000 hours of successful coal-fired operation. Particulate and gas phase sampling up- and down-stream of the APF system indicates a 40-percent reduction in the flue gas sulfur caused by excess sorbent in the dust-cake, and a particle capture efficiency of 99.993 percent [6]. Additional pilot-scale testing with the APF is planned at the circulating PFBC located in Karhula, Finland and at the PSDF to assess filter-system and filter component performance.

Pall Advanced Separations Systems (PASS), through Pall Corporation (Cortland, NY), is offering a candle-filter-based barrier filter system. This system can be either a single tube sheet design or a "porcupine design," both of which can be equipped with a filter fail-safe device [7]. The porcupine design has a higher filter-surface-to-vessel-volume ratio than a single tube sheet design and is intended for larger high-temperature flows. Either design can accommodate ceramic or sintered metal filters, depending on gas composition and temperature. PASS is a manufacturer and distributor of several types of candle filters and will be supplying the slip-stream filter vessel for the Tampa Electric CCT Demonstration project.

The filter system of Industrial Filter & Pump Manufacturing Company (IF&P) (Cicero, Ill) has candle filters that are suspended from a single tube sheet [8]. The IF&P system incorporates a ceramic tube-sheet design, which allows the system to operate at higher temperatures. IF&P is a distributor of the light weight Fibrosic™ filter. The IF&P filter system will be tested at the PSDF. Additionally components of the IP&F filter system will be evaluated in an upcoming pilot-scale test program at the Energy & Environmental Research Center (EERC) at the University of North Dakota.

Barrier-Filter Component Development

Barrier-filter component development has evolved into three general areas: (1) commercially available candle-filter components, (2) advanced candle-filter components, and (3) filters with high surface-to-volume ratios.

Commercially Available Candle-Filter Components. There are at least six commercially available candle filters. The Coors filter is a monolithic-oxide ceramic composed of mullite, anorthite, and alumina. The oxide nature of the material suggests that it will have superior resistance to chemical degradation. The material has been tested in significant pilot-scale tests, including pre- and post-test material characterization [4,9]. Coors Ceramics Company (Golden, CO) has significant production capability for this product.

Both Refractron Technologies Inc. (Newark, NY) and Schumacher GmbH (Schumacher Filters America, Inc. Ashville, NC) manufacture a clay-bonded silicon-carbide candle filter. Both filters have received significant pilot- and demonstration-scale testing [4,5], including pre- and post-test material characterization [9]. Both materials are made of silicon carbide grains that are held together with a clay based binder. Both companies have recently made significant progress towards improving the creep-resistant properties of their material. Pall Corporation is the sole distributor of the Refractron Technologies Inc. product, and Schumacher Filters America Inc. distributes the German-made product.

Industrial Filter & Pump Mfg. Company supports the manufacturing of the Fibrosic™ candle filter. The element is vacuum-formed with chopped aluminosilicate fibers, which produce a light weight filter. The Fibrosic™ filter is being evaluated under a METC contract [10] and has been selected for testing at the PSDF.

3M Company is offering a composite filter that is formed by infiltrating a nextel cloth preform with pure vapor-phase silicon carbide. 3M Company, DOE's Advanced Research and Technology Development Program, and Oak Ridge National Laboratory were instrumental in developing this filter. METC was instrumental in gaining access to field demonstrations for the 3M product [5,9] and the reporting of some performance results [10]. 3M company has recently increased their commercial production capability and is distributing their product on a worldwide basis.

With the advent of super-clean high-temperature desulfurization systems, it is now possible to use high alloy stainless steel as a sintered metal candle filter. Pall Corporation is supplying its PSS 310 SC sintered metal filter elements for the Tampa Electric Clean Coal Project. The filters will operate downstream of a General Electric sulfur removal system at approximately 550 °C and at less than 100 ppm_v of H_2S [7].

Advanced Candle-Filter Components. METC has awarded five filter-component fabrication efforts under a Program Research Development Announcement (PRDA) to develop toughened advanced hot gas filters. The awards made under the PRDA represent several classes of materials, including oxides, non-oxides, continuous fiber ceramic composites (CFCC), and a sintered metal. Some of the manufacturers within this group are filter-system suppliers (Westinghouse Science & Technology Center, Babcock and Wilcox, and Pall Corp.). The selected awards should advance basic material development to deployment readiness as filter components.

The Dupont Lanxide (Newark, DE) PRD-66 oxide ceramic material is derived from wound fibers that contain alumina, mullite, cordierite, and a glass phase [11]. The microstructure of the material is microcracked, providing resistance to thermal stresses. Although the material is still being developed, early success has resulted in some field testing and some post-test characterization of full-size candle filter elements [9,10].

Westinghouse Science & Technology Center (Pittsburgh, PA) and Techniweave Inc. (Rochester, NH) have teamed up to design and fabricate an oxide composite filter [12]. This candle filter component is a 3-D woven Nextel fiber (3M aluminosilicate product) that is infiltrated with mullite using a sol-gel process. The need for a fiber interface coating on this filter is still being assessed. The filter is still in the early stages of development.

Textron Specialty Materials (Lowell, MA) is producing a non-oxide continuous fiber ceramic composite (CFCC) [13]. The filter is a filament-wound (Textron SCS-6 SiC fiber) element that is processed to form a nitride-bonded silicon-carbide composite. The toughened properties of this material are produced by the SCS-6 fiber pull-out. This fiber provides the appropriate matrix-fiber-interface properties without additional fiber coatings. This filter component is still in the developmental stage.

Babcock and Wilcox (Lynchburg, VA) is fabricating an oxide-based, continuous-fiber, ceramic, composite candle filter [14]. This filter element is a filament-wound alumina-based fiber, infiltrated with chopped fibers that form the filtration surface.

Pall Aeropower Corporation, a part of Pall Corporation, is fabricating an iron-aluminide sintered metal filter [15]. The iron-aluminide material was developed through DOE and Oak Ridge National Laboratory. The material has metal-like properties, but is more tolerant of the hydrogen sulfide found in the reducing atmosphere of gasification systems.

While not part of the above mentioned PRDA Dupont Lanxide Composites is developing a silicon carbide—silicon carbide composite. This filter is composed of silicon carbide fibers that are coated with pure silicon carbide through a chemical vapor infiltration process. A fiber-matrix interface coating is used. Chopped fibers make up the filtration surface.

Filters With High Surface-to-Volume Ratios. Other filter geometries are being considered under the barrier-filter-component development program, including filters with high surface-to-volume (SV) ratios. Filters with high SV ratios generally perform filtration on the surface of internal channels of the element. These filters are attractive since they allow filter system packagers to increase the available filtration surface per filter vessel while decreasing the number of filter elements. Filter cleanability and cleaning frequency appears to be the limiting factors, in the successful development of filters with high SV ratios. This group of filters includes the CeraMem (CeraMem Corp., Walthham, MA), Westinghouse Cross Flow, Techniweave Inc. and others.

Ash and Char Characterization

PFBC ash and gasification char are being collected and characterized from bench-, pilot-, and demonstration-scale test facilities under the Particulate Cleanup Program. The purpose is to understand the chemical and physical properties of the filtered particulate in order to predict filter system performance. Particulate chemistry, morphology, size distribution, filtrate temperature, and filtrate chemistry are all important parameters in predicting filter system performance and dust behavior. In conjunction with contract research activities in this area, some of which are described below, METC is also conducting its own in-house research effort to characterize the physical and chemical properties of ash and char.

Southern Research Institute (SRI) (Birmingham, AL) has been awarded a contract to develop a database of ash and char characteristics. The characteristics of both the particles and the dust cake include measurements of aerodynamic diameter, particle density, uncompacted bulk porosity, estimated dust-cake porosity, specific surface area of the particle, particle morphology factor, drag-equivalent diameter, dust-cake tensile strength, and dust-cake relative gas-flow resistance. SRI will also be involved in the isokinetic sampling and characterization of particulate from the PSDF.

The Westinghouse Science & Technology Center recently completed a study on the performance of dust cake modifiers and dust cake reactivities with gas phase chemistry [16]. Their report also provides measurements of dust-cake flow resistance for various PFBC systems.

METC supports an international consortium of participants who are evaluating ash and char from various pilot-, demonstration- and commercial-scale power systems. The consortium is jointly funded by DOE/METC, the Electric Power Research Institute, the EERC, and several international sponsors. EERC is facilitating the resolution of the consortium's research objectives through laboratory-, bench-, and pilot-scale testing, field sampling and predictive models.

Test Schedule

Figure 1 shows the test schedule for the IGCC and PFBC CCT projects, the PSDF, and other pilot-scale tests that will use hot gas particulate filtration. METC is using the pilot-scale tests to resolve technical issue and support the CCT projects.

Pall Advanced Separations System (PASS) will be supplying the filter system to the Tampa Electric CCT project (300 MWe net). The Tampa Electric project is utilizing a Texaco oxygen-blown entrained gasifier with a hot gas cleanup system that operates on a 10-percent slip stream of the total plant flow. The PASS filter will follow a General Electric high-temperature sulfur-removal system. The low sulfur concentration (up to 100 ppm$_v$ H_2S) and the relatively low filtration temperature (550 °C) will make it possible to use 310SC sintered stainless-steel filters. The system is designed with a single tube sheet and the sintered metal filters can be replaced with ceramic filters. Testing is scheduled to start in mid-1996.

The Pinon Pine CCT project will utilize a Westinghouse APF on the full plant flow from a 95-MWe (net) KRW air-blown fluid-bed gasifier. The filter will house four cluster assemblies, each with four levels of plenums. The filter will nominally operate at 1,000 °F and 270 psia. Westinghouse has selected the Refractron Technologies Inc. clay bonded silicon carbide candle filter for this application. The filter represents the largest high-temperature filter system ever designed and built in the U.S. Start-up is scheduled for early 1997.

Both the DMEC-1 first-generation and the Four Rivers second-generation PFBC [17] CCT projects will utilize a Westinghouse APF. Start-up dates of the PFBC CCT Projects are still under negotiation.

The PSDF, located in Wilsonvile, Alabama, will demonstrate two advanced coal-conversion processes and test three different filter designs [18]. The coal conversion process will include the Foster Wheeler second generation PFBC and the MW Kellogg transport reactor. Filter systems to be tested include the Westinghouse APF, the IF&P ceramic tube-sheet system, and Combustion Power Company's granular bed filter. The PSDF will be used to assess filter-system performance under various operating conditions and to advance the development of barrier filter components. The transport reactor is scheduled to start operating towards the end of 1995, and the second generation PFBC is scheduled to start operating during the middle of 1996.

Pilot-scale testing of particulate cleanup systems is planned at three different facilities. The Ahlstrom test facility in Karhula, Finland, will be operated in conjunction with a Westinghouse APF. This test is sponsored by EPRI, Pyropower Corporation, the State of Illinois, Argonne National Laboratory, and DOE/METC. The main test objective will be to asses the high-temperature (1,650°F) performance of four different candle filters. This test will be conducted in a manner similar to past tests [4]. The filters tested will include both clay-bonded silicon-carbide types of filters produced by Schumacher GmbH and Refractron Technologies Inc., the 3M composite, and the Coors candle filter. The test is scheduled to start in late 1995, and plans are to accumulate 1,000 to 1,500 hours of operation.

A test campaign has been scheduled with the EERC. A pilot-scale (200 lb/hr) transport reactor will be used to generate a gas stream under reducing conditions. The dirty gas stream will be delivered to a filter vessel housing a single IF&P ceramic tube sheet that supports 18 candle filters. The 18 elements will comprise three groups of six each and will include the Pall iron-aluminide sintered metal, the 3M composite, and the IF&P Fibrosic™ candle filters. A 200-hour test is scheduled to begin in November 1995, with additional tests possible in 1997.

Tests using the METC advanced 10-inch fluidized-bed gasifier will resume near the end of 1996. As in the past, the METC reactor will be used to support Cooperative Research and Development Agreements (CRADAs). The purpose will be to assess barrier type filters under reducing gas conditions. Several 200-hour test campaigns are planned for 1997.

Technical Issues

Table 1 shows some of the developmental issues facing the commercialization of high-temperature particulate-removal systems. The issues are grouped by program area; i.e., filter systems, barrier filter components, and ash and char properties. Some of the information needed to resolve these issue has been obtained during the past 3 years. DOE/METC will continue with the planned program in particulate cleanup so that these issues can be resolved.

Summary

DOE/METC has developed an integrated particulate-cleanup program that is based on RD&D needs. The program approach is structured around three technical areas: filter systems, barrier filter components, and the characterization of ash and char properties. The issues within these technical areas have been identified, and they drive the details of the RD&D program. As these issues are resolved, the METC Particulate Cleanup Program will move closer to achieving the program objective, which is to ensure the success of the Clean Coal Demonstration Program.

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Table 1. Issues Facing Hot-Gas-Particulate Cleanup Technology

Filter System	Barrier Filters	Ash and Char
• Systems must be robust • Designed for 30-year life • Easily accessible for maintenance • Provide a filter fail-safe approach • The testing of small-scale filter module designs must represent commercial-scale modules • Throughput in GBF systems/ancillary equipment	• High-temperature (above 1,400 °F) creep • Long-term thermal and chemical degradation • Thermal shock and thermal fatigue • Composite filter fiber-matrix interface requirements • Cost per element • Filter surface-to-volume ratio for internal filtration	• Optimum particle size for filter performance • Physical and chemical properties of char • Dust cake reactivity as a function of composition and filtrate temperature and chemistry • Properties of filtered sorbent fines • Effect of vapor-phase alkali

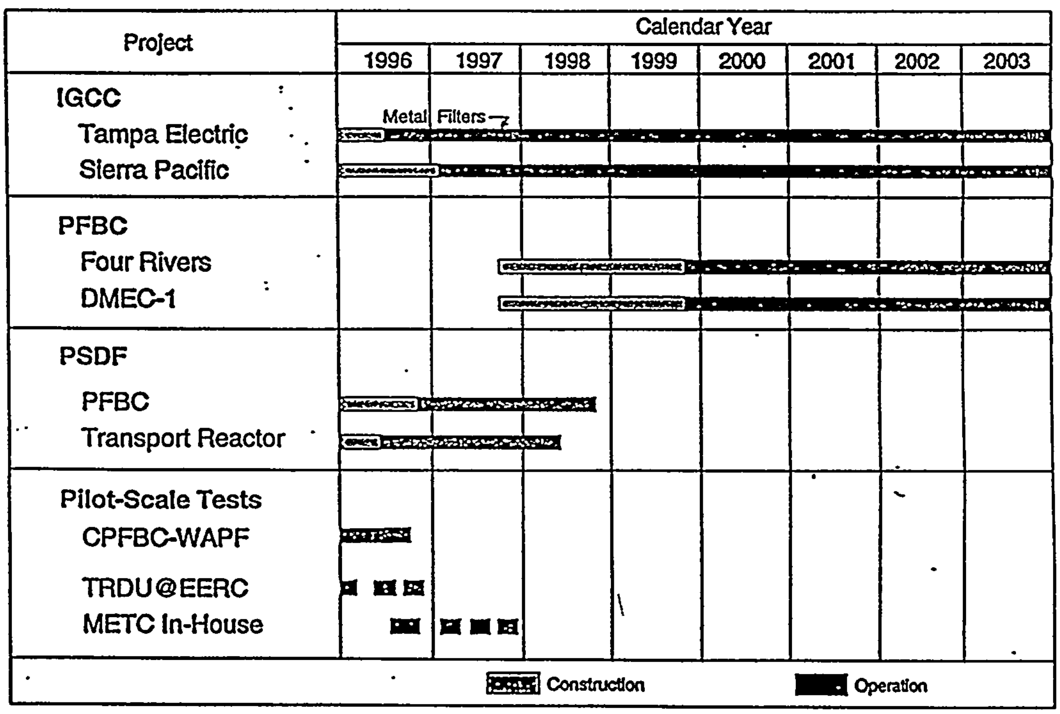

Figure 1. Scheduled Tests Using High-Temperature Filters