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Westinghouse Advanced Particle Filter System

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3.1 Westinghouse Advanced Particle Filter System

CONTRACT INFORMATION

Contract Number	DE-FC21-89MC21023 DE-FC21-89MC26042 DE-FC21-90MC25140
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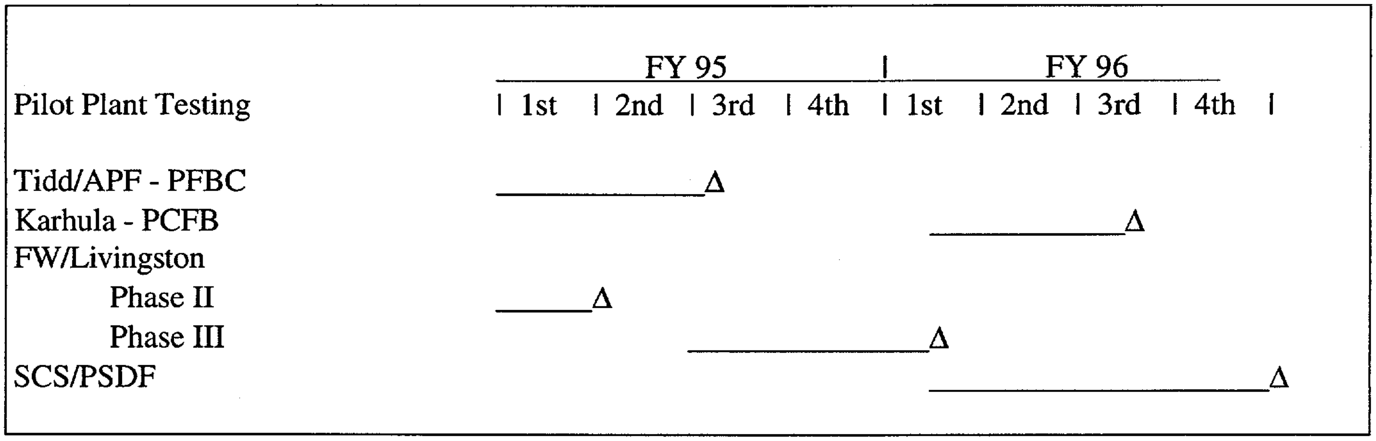
Period of Performance	October 1992 thru September 1997
Schedule and Milestones	

Schedule and Milestones
by Quarter



OBJECTIVES

Integrated Gasification Combined Cycles (IGCC), Pressurized Fluidized Bed Combustion (PFBC) and Advanced PFBC (APFB) are being developed and demonstrated for commercial power generation application. Hot gas particulate filters are key components for the successful implementation of IGCC, PFBC and APFB in power generation gas turbine cycles. The objective of this work is to develop and qualify through analysis and testing a practical hot gas ceramic barrier filter system that meets the performance and operational requirements of these advanced, solid fuel power generation cycles.

BACKGROUND INFORMATION

High temperature particulate filters are a key component in advanced, coal based gas turbine cycles (IGCC and PFBC) that are currently under development by DOE/METC for clean coal demonstration. In these applications the hot gas particulate filter protects the downstream heat exchanger and gas turbine components from particle fouling and erosion effects and cleans the gas to meet particulate emission requirements. Both PFBC and IGCC plants benefit because of lower cost downstream components, improved energy efficiency, lower maintenance and the elimination of additional and expensive flue gas treatment systems.

In IGCC systems, the hot gas particulate filter must operated in reducing gas conditions (i.e., presence of H_2, CH_4, CO), high system pressure (150 psi to 350 psi) and at operating temperatures usually determined by the method of sulfur removal, i.e., in bed, external or by cold gas scrubbing, Figure 1. Typically, these temperatures range around 1650°F (in bed), 900

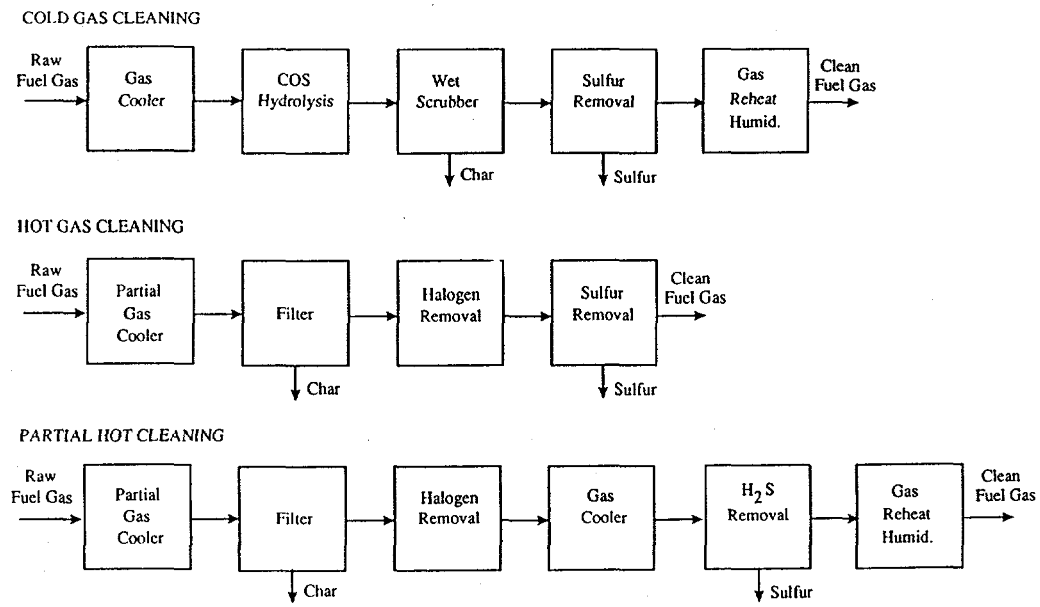


Figure 1. IGCC - Fuel Gas Cleaning Options

to 1200°F (external) and 1000°F to 500°F (cold scrubbing).

In gasification applications, cold scrubbing of the fuel gas has been demonstrated as effective in cleaning the fuel gas to meet turbine and environmental requirements. However, with this process, plant energy efficiency is reduced, and higher capital costs are incurred. Incorporating a hot particulate filter upstream of the scrubbing unit reduces heat exchanger costs and provides for dry ash handling (partial hot gas cleaning).

Hot fuel gas cleaning concepts (in bed and external) have also been proposed that utilize reactive solid sorbents to remove gas phase sulfur and hot gas filters to collect the ash and sorbent particles. This approach in IGCC provides for highest energy efficiency and lowest cost of electricity.

IGCC systems may utilize air or oxygen blown entrained or fluid bed gasifiers. Specific operating conditions of the hot gas particulate filter will vary depending on these choices. In general, hot gas filter pilot plant test experience suggests that gasifier ash/char is noncohesive with relatively high flow resistance. Thus, the potential for fines reentrainment and high filter pressure drop are reduced by selecting a relatively low design filter operating face velocity (<5 ft/min). Since the filter treats only the fuel gas component of the total gas flow, the choice of a low filter face velocity does not adversely impact economics. Typically, for a 100 MW_e IGCC system, the filter is required to treat only 6000 to 12,000 acfm, depending if the gasifier is oxygen or air blown. Inlet dust loadings may also vary widely, ranging from <1000 ppmw to 10,000 ppmw.

Bubbling bed PFBC technology is currently being demonstrated at commercial scale. Two PFBC units are located in Sweden (Stockholm Energi, Vartan Plant), another one at the Endesa's Escatron Plant in Spain and one in the United States at the American Electric Power's (AEP Tidd Plant located in Brilliant, Ohio. The Tidd PFBC is a 70 MW_e demonstration plant awarded through the Round 1 of U.S. DOE Clean Coal Technology Demonstration Program. Currently, all four plants utilize high efficiency cyclones to remove greater than 95% of the ash and a ruggedized gas turbine to tolerate ash carried over from the upstream cyclones. Economic and performance improvements in these first generation type PFBC plants can be realized with the application of hot gas particulate filters. Both the secondary cyclone(s) and stack gas ESP(s) could be eliminated saving costs and providing lower system pressure losses. The cleaner gas (basically ash free) provided with the hot gas filter, also permits a wider selection of gas turbines with potentially higher performance.

For these bubbling bed PFBC applications, the hot gas filter must operate at temperatures of 1580°F and system pressures of 175 psia (conditions typical of the Tidd PFBC plant). Inlet dust loadings to the filter are estimated to be about 500 to 1000 ppm with mass mean particle diameters ranging from 1.5 to 3 μm. For commercial applications typical of the 70 MW_e Tidd PFBC demonstration unit, the filter must treat up to 56,600 acfm of gas flow. Scaleup to about 310 MW_e would require filtering over 160,000 acfm gas flow. For these commercial scale systems, multiple filter vessels are required. Thus, the filter design should be modular for scaling.

An alternative to the bubbling bed PFBC is the circulating bed concept. In this process the hot gas filter will in general be exposed to higher operating temperatures (1650°F) and higher (factor of 10 or more) particle loading. Although the inlet particle loading is high, it contains a significantly coarser fraction (mass mean generally >15 μm) which helps mitigate the effect of the higher mass loading. For a 75 MW_e commercial scale circulating bed PFBC plant, gas flow to the filter is approximately 70,000 acfm. At this scale, multiple vessels with modular filter subassemblies are required.

Second generation or topping PFBC is being developed and planned for demonstration and commercialization. In this plant, higher (than first generation PFBC) turbine inlet temperatures are achieved by partially devolatilizing the coal in a carbonizer unit producing a fuel gas. The char produced is transferred and burned in a circulating PFBC unit with high excess air. The hot (1600°F) vitiated air produced is used to combust the hot fuel gas to raise the combustion gas temperature to as high as 2350°F (Robertson, et al., 1989). With second generation PFBC, two hot gas filters are required. One filter is used to collect the ash and char material carried over from the carbonizer unit with the hot fuel gas. The second filter is used to remove ash and sorbent particles carried over with the hot vitiated air leaving the circulating pressurized fluidized bed combustor (CPFBC). Both filter units are required to operate at high temperatures (1200 to 1600°F) and high particle loading. The fuel gas filter will operate in reducing gas while the CPFBC filter operates in oxidizing conditions. A 95 MW_e second generation PFBC demonstration plant requires a hot fuel gas flow to its filter of about 8000 acfm and hot vitiated air flow to its filter of approximately 64,000 acfm.

In advanced coal based gas turbine cycles, the hot gas filter must meet the application requirements summarized in Table 1. The hot gas filter must remove sufficient particulate to protect the gas turbine from erosion damage, corrosion and particle deposition and meet power plant environmental emission standards (NSPS). Turbine tolerance estimates and current NSPS requirements are shown in Figure 2. Also shown are ceramic barrier filter outlet particle loading data from subpilot and pilot plant test facilities. This data shows the high performance potential of hot gas ceramic filter devices relative to application requirements. Candle, cross flow and tube filters are examples of ceramic barrier filter devices being developed for high temperature particle filtration. These filter devices are basically absolute filters on ash material, can be operated at high gas throughput and can be cleaned by simple pulse jet methods.

Table 1. Hot Gas Filter Application Requirements

- Effective Filter
  - Meet NSPS
  - Protect Downstream Equipment
- Operate Reliably
  - Cleanable
  - Stable Pressure Drop Characteristics
- Robust
  - Oxidizing/Reducing Environments
  - Alkali/Acid Gas
  - Thermal Cycling

PROJECT DESCRIPTION

Westinghouse is developing a high temperature particulate filter system for application in IGCC and PFBC, advanced power generation systems.

Hot Gas Filter System

The Westinghouse hot gas filter design, shown in Figure 3, consists of stacked arrays of filter elements supported from a common tubesheet structure. In this design, the arrays are

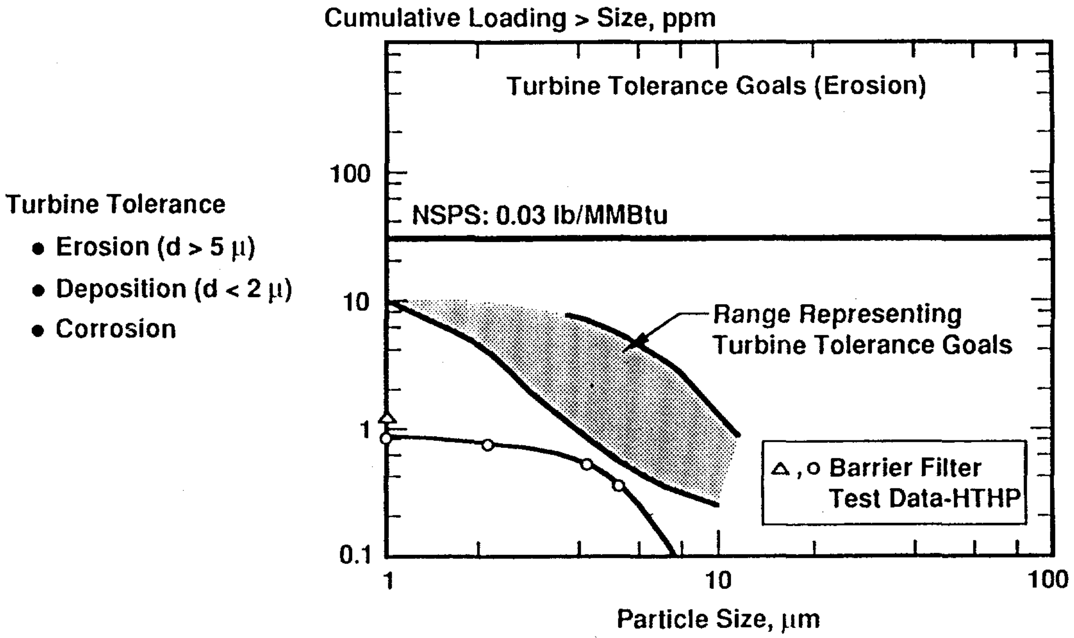


Figure 2. Turbine Tolerance and Particulate Emission Requirements in Coal Fueled Gas Turbine Applications

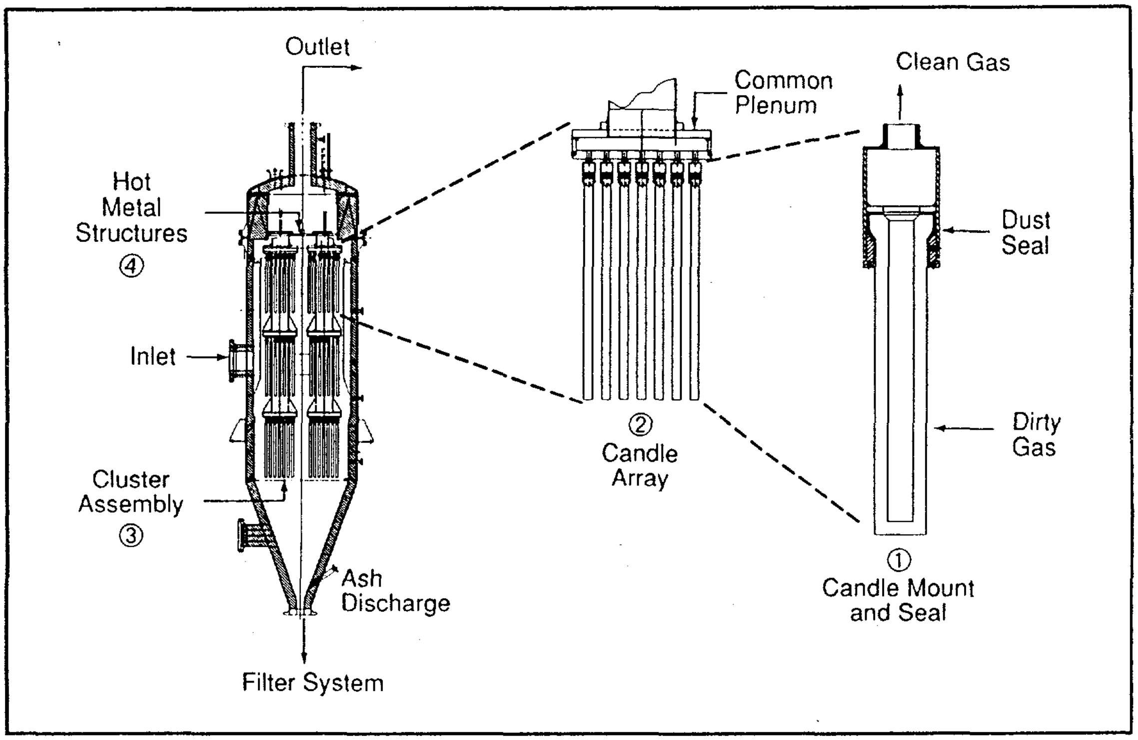


Figure 3. Hot Gas Cleaning Systems - Westinghouse Candle Filter System

formed by attaching individual candle elements (Item 1) to a common plenum section (Item 2). All the dirty gas filtered through the candles comprising this single array is collected in the common plenum section and discharged through a pipe to the clean side of the tubesheet structure. Each array of filter elements is cleaned from a single pulse nozzle source. The individual plenum assemblies (or arrays) are stacked vertically from a common support structure (pipe), forming a filter cluster (Item 3). The individual clusters are supported from a common, high alloy tubesheet structure and expansion assembly (Item 4) that spans the pressure vessel and divides the vessel into its "clean" and "dirty" gas sides. Each cluster attaches to the tubesheet structure by a specially designed split ring assembly. The cluster is free to grow down at temperatures. The plenum discharge pipes ducting the filtered gas to the clean gas side of the tubesheet structure are contained within the cluster support pipe and terminate at the tubesheet. Each discharge pipe contains an eductor section. Separate pulse nozzles are positioned over each eductor section. The eductors assist pulse cleaning. During cleaning, the pulse gas is contained within and ducted down the discharge pipe and pressurizes the respective plenum section.

The plenum assembly and cluster (stacked plenums) form the basic modules needed for constructing large filter systems indicative of PFBC requirements. The scaleup approach is:

- Increasing plenum diameter (more filter elements per array)
- Increasing the number of plenums per cluster
- Increasing the vessel diameter to hold more clusters

In general, vessel diameter will be limited by the tubesheet structure and desire to shop fabricate the vessel. Larger PFBC plants would utilize multiple vessels.

Filter Technology

Ceramic barrier filter devices, such as candles and cross flow filters, are under development for hot gas filter application. These devices have been shown to be basically absolute filters on ash material, can be operated at relatively high gas throughput with acceptable pressure drop and cleanable by simple reverse pulse jet methods. Clay bonded silicon carbide (SiC) candle filters are commercially available. The structure of these elements is mainly a coarse-grained SiC bonded by a clay-based binder. Each element is provided with a fine grained SiC or aluminosilicate fiber outer skin that serves as the filtration surface. Alternate, oxide-based ceramic materials are also being developed for ceramic barrier filter application. Both first generation, full-scale cross flow and candle filter elements have been constructed using a homogeneous structure that is an alumina/mullite (A/M) matrix containing a small percentage of amorphous (glass) phase. Laboratory and field evaluation of these and other materials are being conducted to identify, characterize and compare their respective chemical and thermal stability for IGCC and PFBC applications (Alvin et al., 1993).

This paper updates the assessment of the Westinghouse hot gas filter design based on ongoing testing and analysis.

An important aspect of the filter system development includes the selection and qualification of the ceramic filter element and the implementation and integrated operation of these filters in pilot plant facilities (Lippert et al., 1993).

The qualification and commercialization of the Westinghouse hot gas filter system is being supported through key subpilot, pilot and demonstration programs.

This paper provides a summary of Westinghouse test experience to date focusing on key technology areas. Table 2 provides a summary of Westinghouse subpilot and pilot plant IGCC and PFBC hot gas filter testing experience. Westinghouse currently has accumulated over 2400 hours of ceramic barrier HGF operating experience in gasification environments, both fluidized bed gasification and entrained gasification. In PFBC environments, Westinghouse has accumulated over 8700 hours of experience. In addition to this field experience, over 25,000 hours of test experience has been compiled in Westinghouse HGF, high temperature high pressure simulators.

RESULTS

Entrained Gasification

In this program, a subpilot scale hot gas filter was integrated with the 15 tpd (570 kg/hr) Texaco entrained gasification facility located in Montebello California and operated from April 1989 through August 1992. Filter testing was in support of a base program that was focused on evaluating hot desulfurization technologies. In this testing, the filter was used to protect the external sulfur sorbent beds from ash plugging. Initially, cross flow filters were utilized (Lippert et al., 1993). The filter unit was later backfitted with a 19-element candle array. The candles were implemented to provide data on an alternate filter element geometry, thus providing a basis to directly compare and assess operating characteristics. Seventeen (17) of the candles were the Schumacher 1.5-m (5 ft) long clay bonded SiC F40's; two (2) candles were 1-m long prototype designs of the Coors alumina/mullite.

In the candle filter testing, approximately 300 hours of operation on coal were achieved in four separate test runs, Table 3. In this testing, operating face velocities were maintained at relatively low values necessitated by high ash flow resistance and probable occurrence of fines reentrainment. The performance of the unit was determined by inspection between test runs. In general, these inspections (Test Runs 1 thru 3) confirmed candle integrity and absence of dust leaks. At the end of Test Run 4, a greater than 1800°F temperature excursion occurred. Subsequent inspection showed that three candle elements had failed (one of the SiC and the two, 1.0-m long alumina/mullite prototype elements).

Test results show that in the entrained gasification application stable pressure drop operation can be achieved but the ceramic barrier filter system must be sized and designed for relatively low face velocity (<4 ft/min) and high operating pressure drop. No significant differences between the operating characteristics of the cross flow and candle could be identified.

Pressurized Fluidized Bed Combustion

Westinghouse is conducting hot gas filter testing at two different PFBC facilities: at the American Electric Power (AEP) 70 MW_e Tidd-PFBC demonstration plant located in Brilliant Ohio, and in the Ahlstrom 10 MW_t circulating PFBC facility located in Karhula Finland.

In August 1989 a cooperative agreement was signed between Ohio Power Company, through its agent, the American Electric Power (AEP) Service Corporation and the U.S. DOE to

Table 2. Westinghouse IGCC and PFBC Hot Gas Cleaning Testing Experience

Facility	Pressure (psi)	Temperature Range (°F)	Flow (ACFM)	Dust Load (ppmw)	Test Hours
Texaco Gasifier - Cross-flow - Candle	350	1000 - 1400	50 - 110	300 - 25,000	700
KRW Gasifier - Candle	131 - 231	1050	50 - 300	1,000 - 25,000	1300
Foster Wheeler Carbonizer - Cross-flow - Candle	150 - 200	1100 - 1500	100	5,000 - 35,000	400
Foster Wheeler Combustor - Cross-flow - Candle	150 - 200	1100 - 1500	100	5,000 - 35,000	900
AEP Tidd PFBC - Candle	135	1200 - 1550	7,500	600 - 10,000	5,800
Ahlstrom Karhula PCFB - Candle	160	1550 - 1650	3,070	4,000 - 18,000	2,056
SCS Wilsonville (Kellogg, Foster Wheeler) - Candle - Cross-flow - Bag - Parallel Channel	200 - 350	1200 - 1900	1,000 - 1,700	4,000 - 40,000	Startup Late 1995
SPPC, Pinon Pine IGCC Project - Candle	260	1000	13,391	18,000	Design Phase Startup Late 1996

Table 3. Hot Gas Filter Test Experience

Entrained Gasification (Texaco/Montebello)

Operating Parameters	Candles (SiC/Alumina Mullite)	Cross Flow (Alumina Mullite)
Scale (Pilot), acfm	70 to 110	50 to 110
Pressure, psig	350	350
Temperature, °F	1300 - 1500	1000 - 1400 (Excursion 1800)
Face Velocity, ft/min	1.5 - 2.5	1 - 3.5
No. of Filter Elements	17	4 and 8
Inlet Dust Loading, ppmw	650 - 12,350	250 - 22,500
Hours of Operation	300	400
Status	Completed	Completed

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assess the readiness and economic viability of high temperature and high pressure particulate filter systems for PFBC. The hot gas test facility (see Mudd et al., 1992) is a one seventh (1/7) slipstream taken from the Tidd 70 MW_e PFBC Clean Coal Demonstration Plant. The HGF slipstream replaces one of the seven secondary cyclones by taking 100,000 lb/hr of gas from the discharge of one of the primary cyclones, to outside of the combustor vessel, and into the Westinghouse Advanced Particle Filter (W-APF). The gas flows through a backup cyclone, and then is returned to the combustor vessel and rejoins the gas flow exiting the six cyclone strings. The combined gas flow is then expanded through the gas turbine system.

In the slipstream, ash laden gas at 165 psia, 1550°F flows into the W-APF, Figure 3. The W-APF is designed to use up to 384, 1.5-m long candle elements. Ash collected in the filter is discharged to a screw cooler and into a lockhopper which feeds a vacuum pneumatic ash transport system.

The W-APF unit was commissioned in October 1992 utilizing a full complement of Dia Schumalith F40 candle elements. There have been five (5) test periods since initial operation with over 5800 accumulated test hours, Table 4. In test period 4 and 5, several advanced candle filter elements have been tested in limited numbers, Table 5.

In the early operation of the AEP/APF unit (Test Periods 1 and 2) a relatively high efficient, primary cyclone was utilized in front of the hot gas filter unit. Ash inlet loading was relatively low with an ash mass mean diameter of only 1 to 3 µm. This ash was extremely chemically active with the SO_2 and CO_2 and showed a high tendency to sinter to from an extremely hard dust cake. Under these conditions, stable filter pressure drops could not be achieved above about 1450°F. In addition, at operating temperatures between about 1300°F to 1450°F, stable pressure drop could be achieved over long operating periods (hundreds of hours) but ash cake would tend to accumulate on the metal dust sheds and between candles. This would eventually cause candle damage or failure, particularly during cooldown events. Below about 1300°F, the ash reactivity and flow characteristics appeared to improve significantly and the filter unit could be operated without issue.

In Test Periods 3 and 4, the primary cyclone was detuned by injecting air up through its discharge leg. This increased the mass loading and mass mean particle diameter of the ash entering the filter unit. The ash reactivity and flow characteristics, however, did not improve significantly. Visual inspection of the filter showed ash bridging and ash collected on the metal dust sheds.

In Test Period 5, the primary cyclone was taken out of service, dramatically increasing mass loading and the mass mean particle size. Figure 4 compares the particle size distribution for the three cyclone conditions (in-service, detuned, out of service). The APF unit was successfully operated with the primary cyclone out of service even with higher face velocities (see Table 4). Following the 1100 hr test period, visual inspection confirmed that no ash bridging was evident and the dust shed completely clean of ash buildup.

During Test Period 3, key filter outlet sampling was conducted. Particle outlet loading was measured and SO_2 data obtained upstream and downstream of the hot gas filter unit. The sampling was conducted by Radian and reported in DCN94-633-021-03. The outlet total particle mass loading was measured at less than 1 ppm.

Table 4. Summary of Westinghouse PFBC Hot Gas Filter Testing - Tidd/AEP

Test Period	1 (10/92 - 12/92)	2 (7/93 - 9/93)	3 (1/94 - 4/94)	4 (7/94 - 10/94)	5 (1/95 - 3/95)
No. of Candles	384	384	384	288	288
Primary Cyclone	In Service	In Service	Detuned	Detuned	Out
Test Period, Hours	464	1295	1279	1705	1110
Operating Temperature, °F	1345 - 1450	1150 - 1450	1200 - 1435	1220 - 1400	1400 - 1550
Nominal Face Velocity, ft/min	4.8 - 6.6	4.8 - 6.6	4.6 - 6.6	6 - 8.8	9.5
Inlet Dust Loading, ppmw	600	600	3200	3200	18000
Ash Mass Mean, μm	1 - 3	1 - 3	5 - 7	5 - 7	27
Measured APF Outlet Loading*			<1.0		

* By Radian (DCN 94-633-021-03)

Table 5. Advanced Filter Elements Under PFBC Testing

Designation	Supplier	Matrix
Vitropore 442T	Pall	Clay Bonded SiC
FT20	Schumacher	Clay Bonded SiC
SiC-Composite	3M	CVI Infiltrated
P-100A	Coors	Alumina/Mullite
PRD-66	DuPont	Filament Wound Oxide

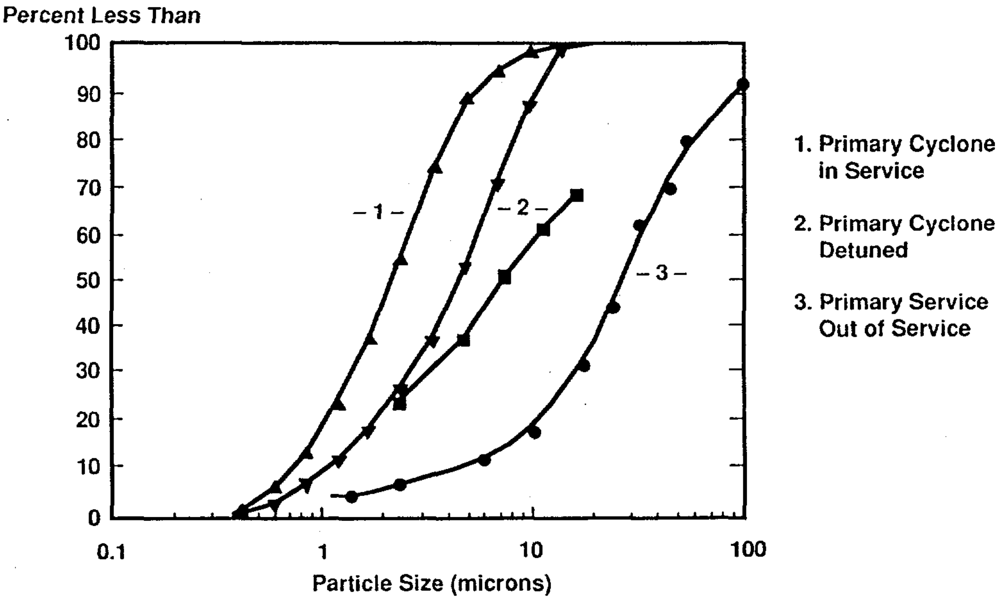

Figure 4. Ash Particle Size Distribution in PFBC/Tidd APF Testing

Results of the SO_2 sampling is given in Table 6. Results showed that across the filter unit an additional 40 to 45% SO_2 removal was achieved.

Through the AEP-PFBC hot gas cleanup cooperative agreement, the U.S.DOE, AEP, Ahlstrom/Pyropower, EPRI and Westinghouse have embarked on a program to also test the W-APF under Pressurized Circulating Fluid Bed (PCFB) conditions. This testing is being conducted at the Ahlstrom 10 MWt PCFB facility located in Karhula Finland, see Lippert et al., 1994. The Westinghouse candle filter installed at Ahlstrom facility consisted of a single 3-array cluster identical to the clusters installed at Tidd, Figure 5. Filter operation was initiated in late October 1992 utilizing a full compliment of 128 alumina/mullite candle filter elements. Operation has included three test segments, achieving approximately 2046 hours of operation, Tables 7 and 8. This testing has included a wide range of coal types and operation to temperatures of 1650°F (900°C). Also, in Test Segments 2 and 3, the alumina/mullite candles were replaced with clay bonded Vitropore 442T SiC elements.

Stable filter pressure drop has also been achieved in the Ahlstrom facility while operating over a wide range of coal/sorbent types and gas temperature to 1650°F (900°C). Figure 6 compares the pressure drop characteristics for the different coal types used in this test program. The stable filter operating conditions in this facility are attributed to the relatively large fraction of ash particles above 10 microns, characteristic of circulating fluid beds. In general, the ash was free flowing and did not accumulate on the metal structures or plenum dust shields. Figure 7 shows the baseline pressure drop for the different coal types over the range of flow conditions tested.

Following the various test runs in both the Ahlstrom and Tidd and PFBC facilities the respective filter units were inspected. In general, these inspections confirmed the effectiveness of the dust seals and integrity of the metal structures. In both test programs extended, trouble-free operating periods have been achieved in which the candle filter units have demonstrated excellent particle collection efficiency.

Topping PFBC

Development of the Topping PFBC (second generation PFBC) is taking place at the Foster Wheeler Development Corporation (FWDC) pilot plant facility located at the John Blizard Research Center in Livingston, New Jersey. The program is in three phases. Phase 1, already completed, developed a conceptual design of the commercial scale plant and identified R&D needs (Robertson et al., 1989). The second phase, also completed, involved separate subscale pilot tests of the carbonizer/filter and combustor/filter. Carbonizer/filter testing occurred in 1992. Combustor/filter testing was completed in 1993. Results of this testing are summarized in Table 9. In 1994 the facility was converted for integrated operation.

During the carbonizer/filter testing, the carbonizer was operated as a jetting fluidized bed unit. Approximately 150 hours of filter operation was achieved. This testing used cross flow filter elements for about 100 hours . Stable filter operation was demonstrated. The carbonizer char showed relatively high flow permeability compared to earlier entrained gasification experience. The char was free flowing and no difficulty was experienced draining the filter vessel.

Table 6. Tidd/PFBC - Hot Gas Filter Sulfur Retention (PPMV SO_2)

	APF		ESP	
	Inlet	Outlet	Inlet	Outlet
Sample 1	----	119	202	202
Sample 2	243	135	193	192
Sample 3	201	114	185	----

Measurements Show 40 to 45% SO_2 Removal
Across Hot Gas Particulate Filter

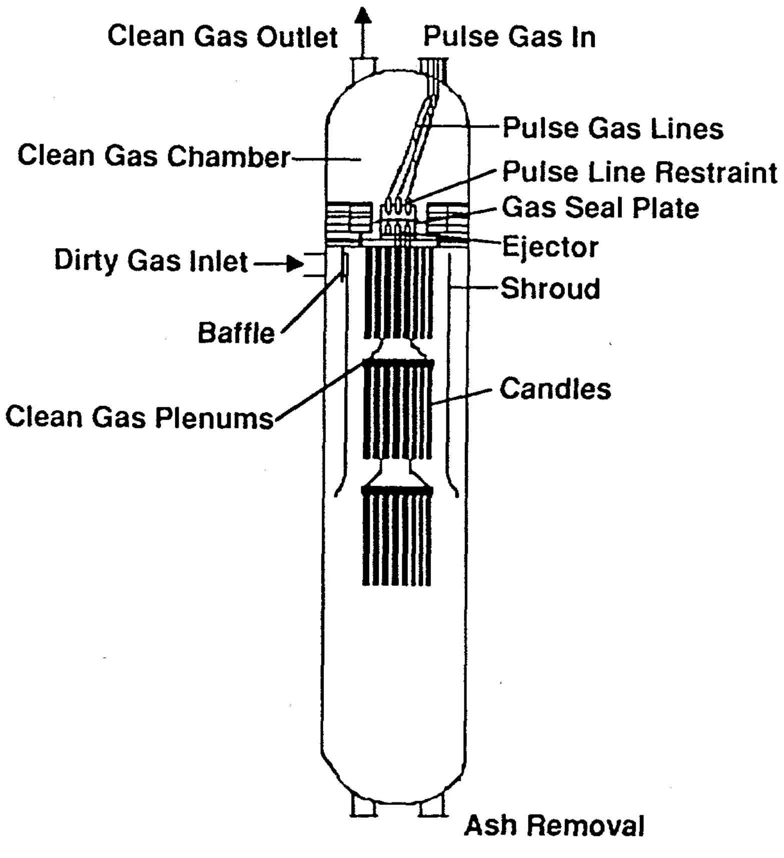

Figure 5. Schematic of PCFB Hot Gas Candle Filter

Table 7. Summary of Westinghouse Hot Gas Filter Operation at the Ahlstrom PCFB Facility - Karhula, Finland

Coal	Segment 1 (Hours)	Segment 2 (Hours)	Segment 3 (Hours)	Total
Illinois No. 6	85	221	--	306
Iowa Rawhide	61	--	--	61
Newland	300	--	--	300
Kentucky	270	--	--	270
Bituminous	--	--	170	170
Pennsylvania	--	--	135	135
Black Thunder	--	291	513	804
Total Coal	716	512	818	2046

Table 8. Summary of Karhula PCFB Testing

	Test Segment 1	Test Segment 2	Test Segment 3
Type of Candles	Alumina/Mullite	SiC-442T	SiC-442T
Operating Temperature, °C	870-900	720-830	690-850
Nominal Face Velocity, cm/s	2.9-4.0	1.7-3.3	1.5-4.0
Inlet Dust Loading, ppm	4,460-13,000	2060-12,300	3000-10,000
Operating Hours	716	512	818

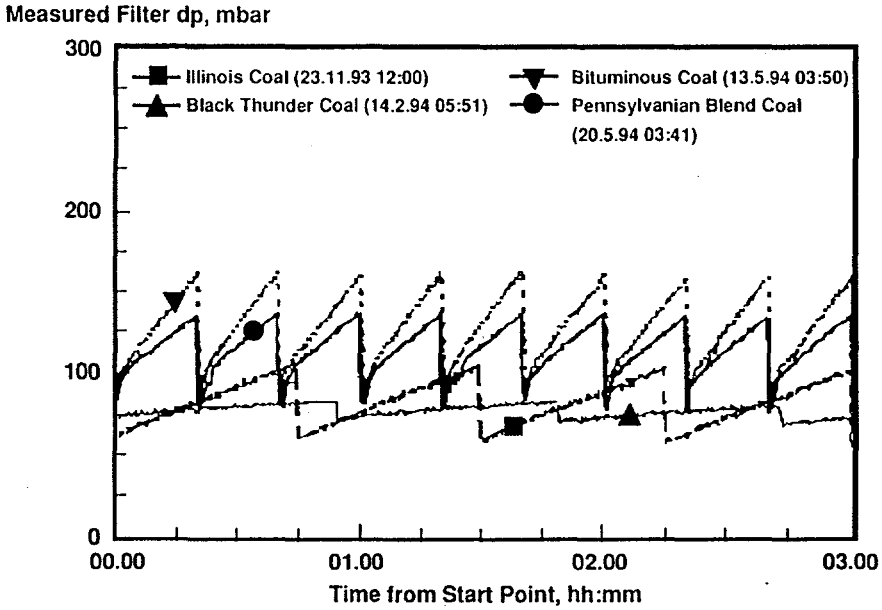

Figure 6. Typical Hot Gas Candle Filter Pressure Drop Characteristics in PCFB Pilot Plant - Test Segments 2 and 3

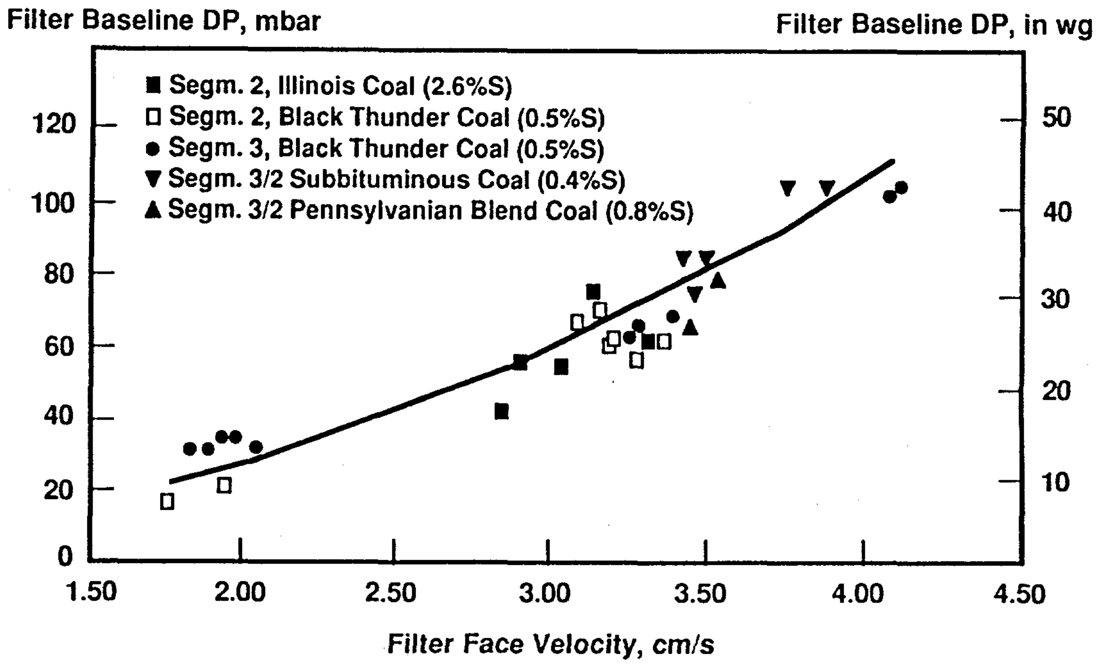

Figure 7. Hot Gas Candle Filter Pressure Drop Characteristics in PCFB Pilot Plant - Test Segments 2 and 3

Table 9. Hot Gas Filter Test Experience

Foster Wheeler - APFB

Operating Parameters	Carbonizer	Combustor
Scale (Pilot)	120 acfm	400 acfm
Type Filters	Cross Flow Candles (SiC)	Candles (A/M) Candles (SiC)
Pressure, psig	100 - 200	100 - 200
Temperature, °F	1100 - 1500	1400 - 1700
Face Velocity, ft/min	1.5	4 - 8
Dust Loading, ppmw	4,000 - 30,000	2,000 - 35,000
Hours of Operation (thru 1994)	150	700
No. Test Runs	3	12
Status	Phase III	Phase III

Following carbonizer testing, the facility was modified to operate in the pressurized circulating fluidized bed combustion mode. The filter unit was configured to a 22-element candle array. Approximately 700 operating hours were accumulated. The PCFB testing included a significant shakedown period (approximately 400 hours) to evaluate PCFB operation and control. During this period the PCFB was tested on both coke and coal and the filter was exposed to severe upset conditions. Candle breakage was incurred in some of the shakedown runs.

The final PCFB test run following shakedown included a 180 hour continuous test period in which the PCFB and filter operated under char and coal fired conditions. In this test, the filter was configured with a 14 candle elements to operate at a face velocity of about 8 ft/min. The PCFB operated smoothly and without major upset. Filter operating pressure drop was stable throughout the test run. Inspection of the filter following completion of the test run showed the 14 candle elements to be undamaged. There was no indication of dust leaks to the clean side. Phase III operation is currently in progress. In this testing, the carbonizer and combustor are integrated. The carbonizer filter is the 22-element candle array previously utilized in the Phase II testing. A second candle filter unit was designed and supplied for the combustor leg. This filter contains 45 candle elements in a two plenum array.

Candle Material Surveillance. Material surveillance programs have been implemented to recover and characterize selected filter elements from the various field test programs. The objectives are to identify the potential long term thermal/chemical effects that advanced coal based power generating systems have on the stability of porous ceramic filter materials and assess the influence of these effects on filter operating performance and life. Most of the current operating experience has been with first generation monolithic porous ceramic candles. The Coors alumina/mullite and clay bonded silicon carbide Pall Vitropore 442T and Schumacher Dia Schumalith F40 candle filters have typically operated between temperatures of 1000°F to 1650°F (540°C and 900°C) in both oxidizing and reducing gas environments representative of advanced coal-fired process applications. Surveillance candles recovered from the pilot plant testing have been destructively evaluated for strength and characterized using SEM/EDAX analytical techniques, (Alvin et al., 1994). A companion paper updates the Westinghouse filter materials development work.

SCS/PSDF - Hot Gas Filters. Westinghouse is designing two hot gas particle control devices (PCD) for installation at the Southern Company Services Power System Development Facility located in Wilsonville, Alabama. Table 10 summarizes the basis for the two PCD designs. PCD 352 will be installed and integrated with the Foster Wheeler circulating PFBC unit. The filter is designed to utilize candle filter elements. Operating experience gained from the Karhula PCFB and Tidd PFBC filter testing have been factored into the PCD 352 design. Improvements include increased spacing between the candle elements and plenum pipe support structure, redesign of the plenum dust shields to enlarge and improve the path for ash discharge; recessing the candle filter holders into the clean gas plenum sections thus eliminating the region where dust can bridge and form clumps that ultimately can break off and get trapped between the candle elements. A steeper cone angle and large outlet flange are also employed in the vessel ash hopper region to promote ash discharge.

Table 10. SCS/PSDF - Westinghouse Hot Gas Filter

HGF Design/Operating Parameters	FW/APFB Combustor	FW/APFB Carbonizer and MWK Transport Reactor
Gas Flow, acfm	2000 to 8800	1000 to 2000
Design Pressure, psig	350	350
Operating Temperature, °F	1200 to 1650	1000 to 1800
Inlet Dust Loading, ppmw	15,000	4,000 to 16,000
Filter Elements	Candles	Candles (Initial)*
No. Elements (Max)	273	91
Face Velocity, ft/min	8 @ 6200 acfm	4.2 @ 1000 acfm
*Options		Cross Flow CeraMem Ceramic Bags

The PCD 301 unit will be initially installed and operated on the M. W. Kellogg transport reactor test module. The PCD 301 is designed to interchange the test cluster to accommodate a variety of filter types including:

- Advanced Candles
- Cross Flow
- CeraMem Axial Cross Flow
- Ceramic Bags

FUTURE WORK

Continued testing of Westinghouse hot gas filter system is planned this summer at the Foster Wheeler APFBC pilot plant facility. Testing of the advanced design PCD 301 and 352 at the SCS/PSDF is scheduled to be initiated in the third quarter in 1995. Results of these and other ongoing filter testing will be utilized to demonstrate and qualify the Westinghouse Advanced Particle Filter for Clean Coal and commercial application.

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