

Paper Number:

DOE/MC/31147-97/C0714

Title:

Westinghouse Advanced Particle Filter System

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Contract Number:

DE-AC21-94MC31147

Conference:

Advanced Coal-Fired Power Systems '96 Review Meeting

Conference Location:

Morgantown, West Virginia

Conference Dates:

July 16-18, 1996

Conference Sponsor:

U.S. DOE, Morgantown Energy Technology Center

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Westinghouse Advanced Particle Filter System

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Abstract

Integrated Gasification Combined Cycles (IGCC) and Pressurized Fluidized Bed Combustion (PFBC) are being developed and demonstrated for commercial, power generation application. Hot gas particulate filters are key components for the successful implementation of IGCC and PFBC 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 PFBC and IGCC systems.

This paper reports on the development and status of testing of the Westinghouse Advanced Hot Gas Particle Filter (W-APF) including:

- W-APF integrated operation with the American Electric Power, 70 MW_t PFBC clean coal facility. Approximately 6000 test hours completed.
- Approximately 2500 hours of testing at the Hans Ahlstrom 10 MW PCFB facility located in Karhula, Finland.
- Over 700 hours of operation at the Foster Wheeler 2 MW 2nd generation PFBC facility located in Livingston, New Jersey.
- Status of Westinghouse HGF supply for the DOE Southern Company Services Power System Development Facility (PSDF) located in Wilsonville, Alabama.
- The status of the Westinghouse development and testing of HGF's for Biomass Power Generation.
- The status of the design and supply of the HGF unit for the 95 MW Pinon Pine IGCC Clean Coal Demonstration.

Results reported include operating history, operating characteristics and filter performance. Schedules and objectives for future testing are summarized.

Introduction

High temperature particulate filters are a key component in advanced, coal based gas turbine cycles (IGCC, Integrated Gasification Combined Cycle and PFBC, Pressurized Fluidized Bed Combustion) 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.

IGCC Systems

In IGCC systems, the hot gas particulate filter must operate 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 to 1200°F (external) and 1000°F to 500°F (cold scrubbing).

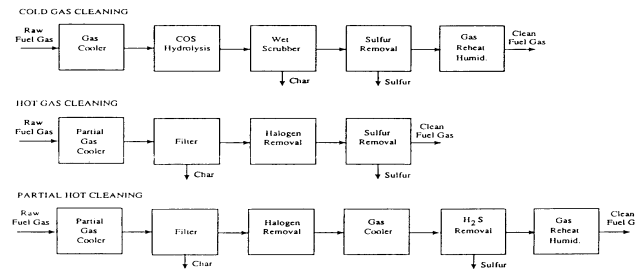


Figure 1. IGCC - Fuel Gas Cleaning Options

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 re-entrainment 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.

PFBC Systems

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 $>15\ \mu\text{m}$) 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.

Objectives

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 Advanced, Solid Fuel Power Generation Cycles, Table 1.

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

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 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 the hot gas ceramic filter device relative to power generation application.

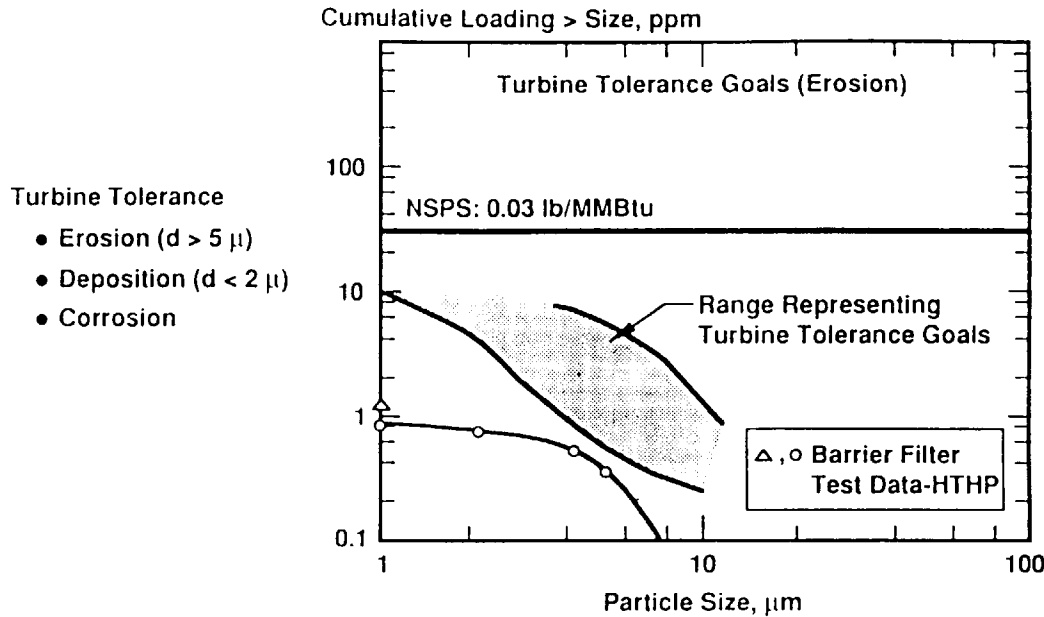


Figure 2. Turbine Tolerance and Particulate Emission Requirements in Coal Fueled Gas Turbine Applications

Candle, crossflow 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 materials, can be operated at high throughput and can be cleaned by simple pulse jet methods.

Project Description

Background

The Westinghouse hot gas filter system is being supported through key sub-pilot, pilot and demonstration programs, Table 2. This testing has included approximately 3150 hours of operation in reducing gas environments (gasification) and 9460 hours in combustion (oxidizing) conditions. In addition to this field experience, over 25,000 hours of test experience has been compiled in the Westinghouse HGF, high temperature, high pressure simulators.

Hot Gas Filter System

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

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

Application	Facility	Pressure (psi)	Temperature Range (°F)	Flow (ACFM)	Dust Load (ppmw)	Test Hours
Gasification (IGCC)	Fluid bed (KRW)	131-231	1050	50-300	1,000 - 25,000	1300
	Texaco Gasifier	350	1000-1400	50-110	300-25,000	700
	Biomass (NREL) IGT/WHBGP	195-260	1000-1650	125	1,000-2,500	500-IGT (Continuing)
	SCS Wilsonville (MWK)	200-350	1200-1900	1000-1700	4,000-40,000	Startup 1996
	SPPC, Pinon Pine IGCC	260	1000	13,391	18,000	Startup 1996
Combustion (PFBC)	AEP Tidd, PFBC	135	1200-1550	7,500	600-10,000	5,800
	Ahlstrom Karhula, PCFB	160	1550-1650	3,070	4,000-18,000	2,056 (Continuing)
Advanced PFBC	FWDC/Livingston • Carbonizer • Combustor	150-200	1100-1500	100-400	5,000-35,000	400 (700)* 900 (700)*
	SCS/PSDF (FW-7MW _i)	200-350	1200-1650	2,000	11,000	Startup 1996/97

*Integrated Operation, 1995

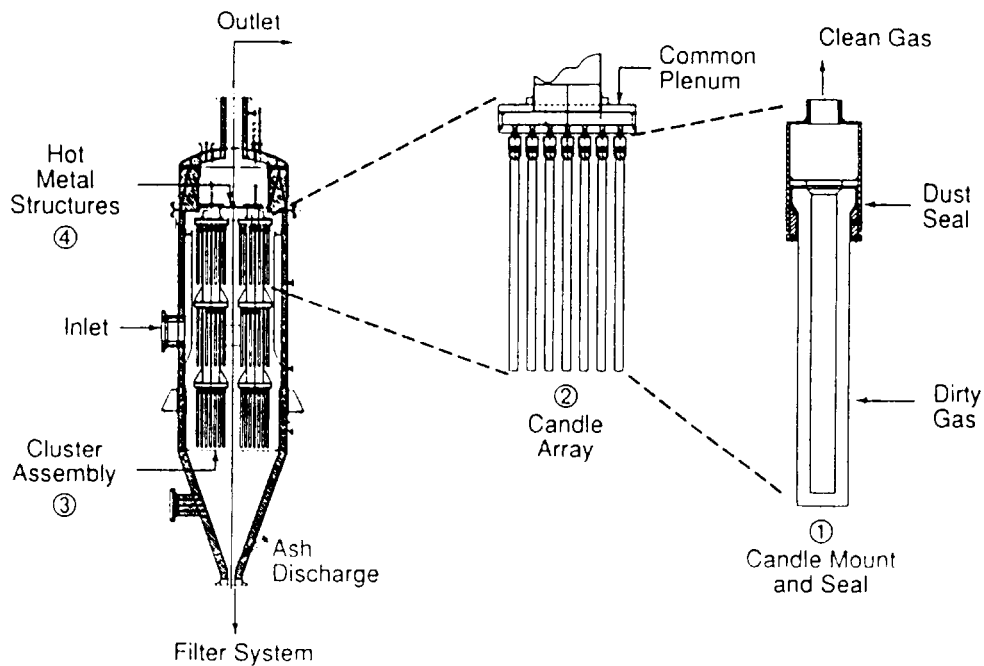


Figure 3. Hot Gas Cleaning Systems - Westinghouse Candle Filter System

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 Element 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. The status of this work is presented in a companion paper entitled “Filter Component Assessment.”

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

Approach

The development and qualification of the Westinghouse hot gas filter is being supported through key sub-pilot, pilot and demonstration projects. Test sites include government furnished and industrial facilities.

Results

Entrained Gasification

In this program, a sub-pilot scale hot gas filter was integrated with a 15 tpd Texaco entrained gasifier. The facility is located in Montebello California. The filter test program was conducted from April 1989 through August 1992 and reported (Lippert et al., 1993). 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. This work showed 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 (>3 or 4 psi).

Biomass IGCC/HGF Testing

A 14 candle-element HGF unit was integrated and operated with the Institute of Gas Technology's (IGT) RENUGAS biomass gasification process. The RENUGAS process is a pressurized fluidized bed, air or oxygen blown gasifier. The development and operation of the IGT's 10 ton per day process development unit (PDU) is described by Wiant, et al., 1993 and Lau, et al., 1993. The testing program at IGT utilized bagasse and alfalfa feed and was conducted in support of the DOE Biomass Power Program, and specifically the Biomass Gasification Facility Demonstration in Paia, Hawaii.

The IGT/PDU included a tar cracker that was first operated and characterized. It was concluded from this work that the majority of the oil and tar from the RENUGAS process would not crack within the pores of the filter elements if the filter temperature is maintained below 1500°F (815°C), but above the condensation temperature of the highest boiling-point components (approximately 950°F (510°C)).

The hot gas filter testing was conducted in two, one week test campaigns resulting in about 50 operational hours at conditions. The testing was sufficient to establish initial performance evaluations and to identify potential longer term issues. A summary of the testing conditions is given in Table 3. Test Series 1 was conducted with the full 14-element complement of candle elements. In this test series, the upstream cyclone was disabled to increase particle size and solid loading to the filter unit. Particle analysis showed a 10.8 micron mass mean. This short duration test showed no operational issues, with stable baseline pressure drop. Visual inspection, following testing confirmed filter integrity and high performance level (high collection efficiency). The filter elements were observed to have a hard reddish pottery-like crusty coating. This coating was apparently a permanent porous coat of iron-rich material deposited during the highest temperature portion of the first test segment. The source of the reddish coating was determined to be dirt in the feedstock.

Table 3. Biomass/IGT Hot Gas Filter Testing Summary

	<u>Test 1</u>	<u>Test 2</u>
Feed Stock	Bagasse	Bagasse
Filter Pressure	1.8 Mpa (260 psig)	1.3 to 1.7 Mpa (195 to 245 psig)
Filter Gas Temperature	860 to 900°C (1580 to 1650°F)	540 to 665°C (1000 to 1230°F)
No. of Candle Elements	14	10
Face Velocity	1.4 cm/s (2.8 ft/min)	0.6 to 2.1 cm/s (1.2 to 4.2 ft/min)
Dust Loading	2900 ppm	980 to 2500 ppm
Operating Hours	21	30
Outlet Dust Loading	Not Detectable	Not Detectable
Alkali	--	0.7 to 1.0 ppm

Test series 2 was conducted utilizing ten candle element and with the upstream cyclone fully operational. Again, particle analysis showed that the mass mean size, 3.8 microns, now entering the filter decreased significantly compared to Test Series 1. Initially, in the Test Series 2 testing, steady filter pressure drop characteristics were observed but in the latter portion of Segment 3, a steady rise in the baseline pressure drop was observed, likely reflecting re-entrainment because of the smaller particle mean size. Post test inspection confirmed the filter integrity and no dust was found on the clean gas side. These test results show that better performance will be achieved with larger particle size, thus eliminating the need for the upstream cyclone.

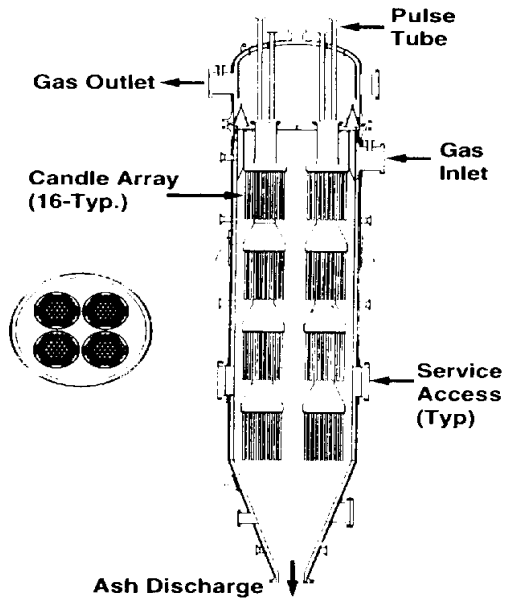
Sierra Pacific, Pinon Pine IGCC/HGF Project

Westinghouse has designed and supplied the HGF unit for the Department of Energy's Clean Coal Technology Demonstration, Pinon Pine IGCC project. The coal gasification process uses the KRW fluid bed technology owned by The M.W. Kellogg Co. who specified and purchased the filter. The final filter design evolved to satisfy the project requirements of both The M.W. Kellogg Co. and the Sierra Pacific Power Co. The plant is located at the Sierra Pacific Power Company's Tracy station near Reno, Nevada. The plant will gassy approximately 880 tons/day of coal using the KRW air blown gasification process to produce about 95 Mwe. The plant is scheduled to begin commercial operation in late 1996.

Table 4 summarizes the design basis for the HGF unit. The unit is schematically shown in Figure 4. The filter consists of 784 candle elements, arrayed on four clusters. Each cluster contains four plenums each with 187 candle elements. The internals are designed using a high silicon stainless Alloy, RA85H, to resist metal dusting, a catastrophic form of carburization.

The filter unit is designed for Seismic Zone 4. To protect the internals from damage due to lateral displacement in the event of a seismic event, the clusters are contained by a set of radially

SPPC – PINON PINE HGF



- 10 Ft. Dia. (3.05 m) Refractory Lined Vessel
- Contains 748 (1.5 Meter Long) SiC Candle Elements
- Candle Elements are Arrayed on Sixteen (16) Plenum Assemblies Containing from 42 to 61 Elements
- Backpulse Cleaning – Recycled Fuel Gas


 STC
 4T355-SQ MZ

Figure 4. SPPC - Pinon Pine HGF

Table 4. SPPC -Pinon Pine HGF Design Basis

Gas Environment:	Reducing
Gas Flow:	307,800 lb/hr/ 139,600 kg/hr
Pressure:	260 psi/18 Bar
Gas Temperature:	1011°F/554°C
Inlet Dust Loading:	18,400 ppm/22 gm/NM ³
Max. Pressure Drop:	9 psi/0.62 Bar
Operating Face Velocity:	5.8 ft/min/2.9 cm/s
No. of Candle Elements:	748 (1.5m)

oriented shoes that fit against the refractory lining. Relative motion between clusters is further restricted by tabs attached at the tangent points between adjoining plenums.

For commercial operation, the Filter is designed for maintainability. Access into the filter body is provided by four, 36 inch diameter manways. Two diametrically opposite manways are positioned between clusters to access the top level of plenums. Similarly, two diametrically opposite manways are positioned between clusters to access the lower middle level of plenums. Platforms were designed to

bolt to the manway flanges to provide staging for personnel to stand inside the vessel for in-situ service work. Below each manway a set of vertically oriented rails are provided. Ladders treads are strung between the rails to provide access to the lower plenum service area. Personnel climb down the ladder and work off a second platform. The arrangement is illustrated in Figure 5. At any given platform location, all filters for two adjacent plenums are accessible by rotating the associated cluster. Such rotation is accomplished by entering the vessel head above the tubesheet, disengaging the cluster top flange from the tubesheet and with standard manual rigging attached between the vessel head and cluster top flange, lifting and rotating the cluster.

Hot Gas Filter Maintenance Features

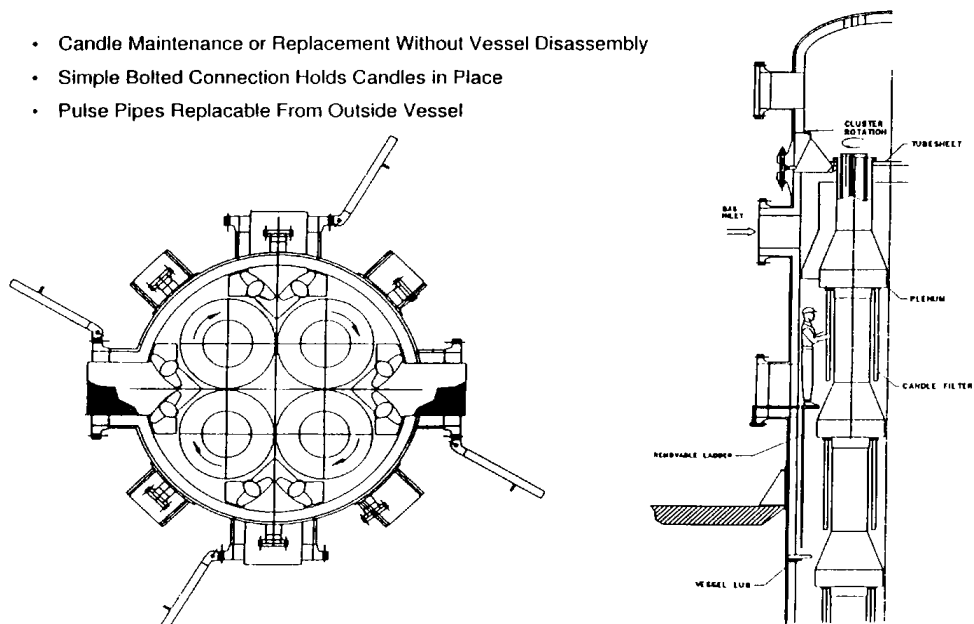


Figure 5. Hot Gas Filter Maintenance Features

The first application of the maintenance hardware was demonstrated at the initial filter installation. Four teams of boilmakers were trained. They worked simultaneously inside the filter vessel and accomplished assembly of all the 748 candle elements, demonstrating the overall approach to maintainability.

Pressurized Fluidized Bed Combustion

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

Testing at the AEP/Tidd has been completed and reported (Lippert, et.al., 1995). In addition, an initial series of HGF tests were conducted at the Karhula PCFB from November 1992 through June, 1994. A description of this facility and discussion of results of this testing has been reported (Lippert et. al., 1995). In November 1995, a second series of tests were initiated utilizing the same Westinghouse candle cluster that was in place for the earlier test programs. The purpose of the current testing is to evaluate several advanced candle materials at operating temperatures between 1550°F to 1650°F. To date, approximately 500 test hours have been accomplished. Materials evaluations are ongoing and reported in a companion paper, "Filter Component Assessment."

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. In 1994 the facility was converted for integrated operation, Phase III.

During the carbonizer/filter testing in 1992, 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 400 hours. Stable filter operation was demonstrated. The carbonizer char showed relatively high flow permeability compared to earlier entrained gasification experience and was free flowing.

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 900 operating hours were accumulated in this testing.

The final Phase II 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 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 no indication of dust leaks to the clean side.

Phase III operation was completed in 1995. In this testing, the carbonizer and combustor were 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 contained 45 candle elements in a two plenum array. Approximately 700 hours of operation was achieved in the Phase III testing.

Development of the topping PFBC will be continued at larger scale at the Southern Company Services, Power Systems Development Facility (PSDF) located in Wilsonville, Alabama. Westinghouse is providing two HGPFs for this facility.

Application

The successful development and demonstration of hot gas particulate filters will enable achieving higher energy efficiencies and lower costs in Advanced Power Generation cycles such as IGCC, PFBC and Advanced PFBC. The technology has application for a wide range of solid fuels, including coal and biomass. In addition, many industrial applications could benefit from HGF technology application.

Future Activities

FWDC/Karhula PCFB

Test operations continue at the FWDC, 10Mwt PCFB facility at Karhula Finland that utilize the Westinghouse HGF candle unit containing up to 128 elements. HGF testing is focused on evaluating alternative candle materials to temperatures above 830°C.

Power Systems Development Facility

Westinghouse has designed and supplied two HGF units (PCD-301 & PCD-352) for installation and operation at the SCS/PSDF. The PCD-301 unit has been installed into the MWK entrained reactor test loop. Operation is expected to begin in the July/August 1996 time frame. Initial operation will be in the combustion mode. The PCD-301 is a two-plenum, single cluster unit containing 92 candle elements. For initial MWK Transport Reactor shakedown operations, the PCD-301 has been fitted with used (from Tidd testing) clay-bonded, SiC elements.

PCD-352 unit has been completely fabricated and delivered to site. This unit will serve as the HGF for the Combustion Leg of the FWDC/APFB test loop. Installation is ongoing, with operation expected early in 1997. The PCD-352 is a 3-Cluster, 2-Plenum unit that can hold up to 273 candle elements. Clusters from the PCD-301 are interchangeable with clusters from the PCD-352 unit. Candles for the PCD-352 have not been selected.

Sierra, Pinon Pine 95 Mwe IGCC

Plant start-up is expected late 1996. The Westinghouse HGF unit is installed and ready for operation.

Acknowledgments

We wish to acknowledge the DOE/METC CTO's involved in the various programs related to the hot gas particulate filter development for their technical guidance and support during the conduct of these programs; Mr. Richard Dennis, Mr. James Longanbach, Mr. Donald Bank and Mr. Theodore McMachon. Also, the following organizations are recognized: Foster Wheeler Development Company; American Electric Power; Southern Company Services; Electric Power Research Institute; M. W. Kellogg Company.

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