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Subpilot Scale Gasifier Evaluation of Ceramic Cross Flow Filter

Final Report
February 1, 1988 - December 31, 1992

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August 1993

Work Performed Under Contract No.: DE-AC21-88MC24021

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Westinghouse Electric Corporation
Science and Technology Center
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ABSTRACT

The operating characteristics, performance and durability of a hot gas cross flow filter system were evaluated at the Texaco 15 tpd, entrained-bed gasifier pilot plant facility that is located at their Montebello Research Facilities (MRL) in California. A candle filter unit was also tested for comparative purposes. A wide range of operating test conditions were experienced. This report summarizes the results of eleven different test runs that occurred from April 1989 through August 1992. Differences between filter operation on the entrained gasifier and prior experience on fluid bed combustion are discussed.

1. INTRODUCTION

High temperature and pressure (HTHP) particulate control is an essential component of advanced coal-fired power generation systems that are under development by the DOE Morgantown Energy Technology Center for clean coal programs and future commercialization. These systems include gasification combined cycles (IGCC), pressurized fluidized-bed combustion (PFBC), and direct coal fueled turbines (DCFT). All of these systems rely on a gas turbine to generate all (or a portion of) the electrical power.

The Texaco coal gasification process is a second generation coal conversion process that utilizes a slagging entrained flow gasifier. This technology has been successfully demonstrated in a 100 MW integrated gasification combined cycle (IGCC) electric power generating plant, as well as in three other commercial installations to produce ammonia and petrochemicals. The use of an advanced gasification system, which is integrated with a combined cycle power plant, results in one of the most promising processes which utilizes fossil fuels in an environmentally acceptable manner. Using coal to generate a fuel gas, however, requires removal of particulates and other gas phase contaminants that could lead to erosion and corrosion of downstream gas turbine components.

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. Hot gas particulate filters can be used with cold gas scrubbing to reduce the capital costs of this approach. Incorporating a hot particulate filter upstream of the scrubbing unit reduces heat exchanger costs and provides for dry ash handling. Hot fuel gas cleaning concepts have also been proposed that utilize reactive sorbents to remove gas phase sulfur (H_2S, etc.) and hot gas filters to collect particulate. This approach provides for highest energy efficiency and lowest cost of electricity.

A schematic representation of one scheme for a Texaco Integrated Gasification Combined Cycle (IGCC) process utilizing hot gas cleaning is shown in Figure 1.1. Hot fuel gases generated during coal gasification are first desulfurized in the in situ cleanup module located either in the gasifier, or in a downstream radiant cooling section. Fuel gas then enters the first filter module which removes the gasifier fly ash and spent sorbent which is released from the primary desulfurizer. The process then allows the particulate free gas to be further processed in sulfur polishing beds for final sulfur removal. A second filter module serves as a guard device located downstream of the sulfur polishing beds to remove fine particulates generated by bed attrition. A third but smaller filter module is provided in order to remove debris released from the beds during regeneration cycles. During the conduct of the Texaco/Westinghouse DOE/METC test program reported herein, the pilot scale hot gas filter (utilizing cross flow and later, candle filter elements) system that was operated at the Texaco Montebello facility utilized the first of these particulate cleanup modules.

Ceramic barrier filters have been identified as a viable particulate control option for use in these coal-based power systems. The ceramic filter elements are near absolute filters, removing >99.9% of the entrained fines, have high throughput capability, are relatively inert to gas phase contaminants, and maintain stability and material strength at high temperatures. These characteristics protect the gas turbine from particle erosion and deposition and clean the fuel gas to meet particulate emission standards without additional expensive stack gas cleanup devices. The cross flow filter concept has been identified as one of the most cost effective technologies for advanced particle filtration.[1] Candle filters are also barrier devices of different geometry that are also being developed for hot gas cleaning. Both cross flow and candles were utilized in the test program described.

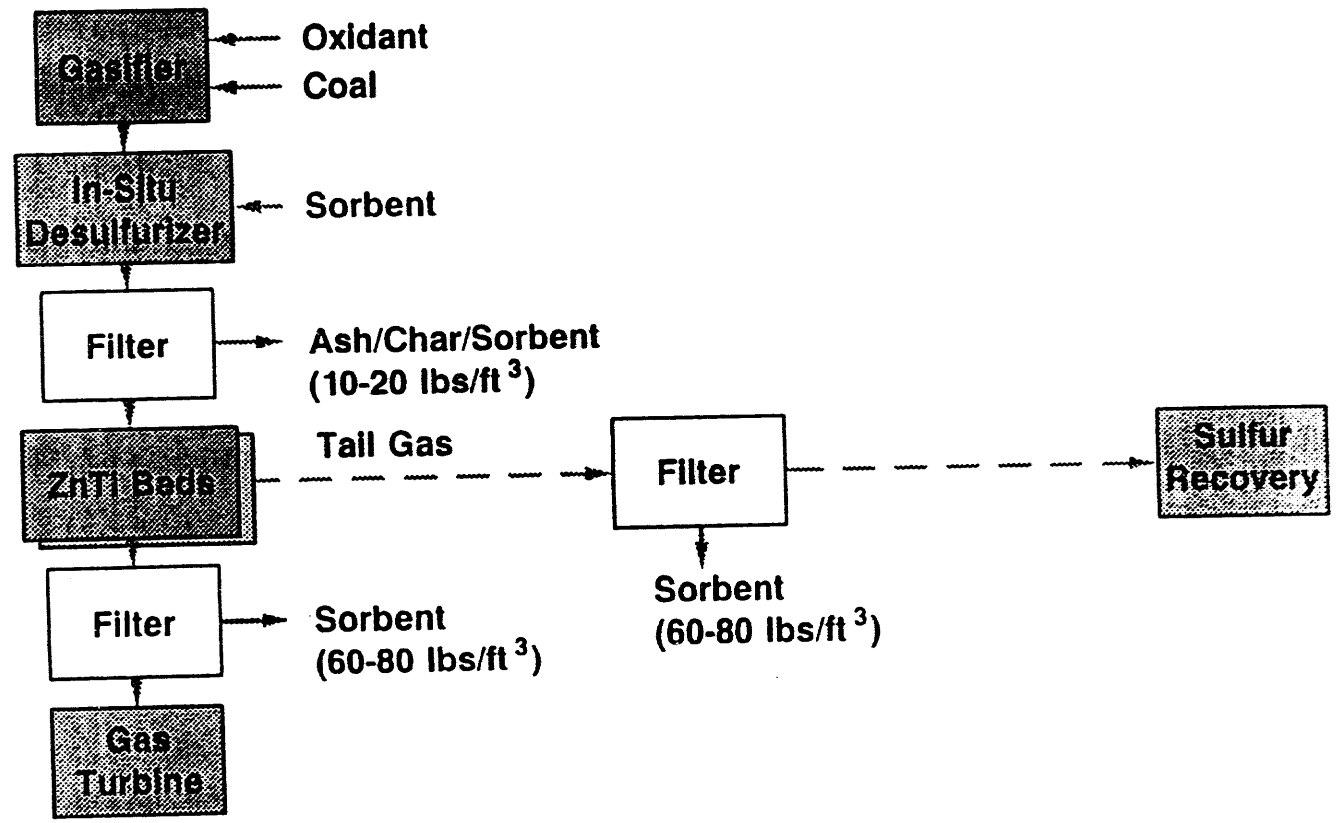

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Figure 1.1 - Schematic of Hot Gas Cleaning Process in IGCC Power Plant

1.1 CROSS FLOW FILTER CONCEPT

The ceramic cross flow filter is illustrated in Figure 1.2. The filter element is comprised of thin porous ceramic plates that contain channels formed by ribbed sections. The plates are stacked and fired to form a monolithic porous structure. The two filter faces of the short side channels are exposed to the dirty gas. The gas and particulate flow into the short side channels, through the porous plates that form the "roof" and "floor" of the channels and into the longer channels that form the clean gas side. One end of the clean side channels is sealed to force the filtered gas to flow to a central collection plenum to which the filter is mounted.

The Westinghouse cross flow filter system design is schematically shown in Figures 1.3 and 1.4. The system consists of a refractory lined, coded pressure vessel that contains arrays of the cross flow filter element assemblies, Figure 1.3. The arrays are formed by attaching individual cross flow elements (Item 1, Figure 1.4) to a common plenum (Item 2, Figure 1.4) and discharge pipe. The arrays are cleaned from a single pulse nozzle source.

For efficient packaging, several of the individual plenum assemblies are arranged vertically from a common support structure, forming a filter cluster (Item 3, Figure 1.4). The filter cluster represents the basic module needed for constructing a large filter system. The individual clusters are supported from a common, high alloy tubesheet and expansion assembly that spans the pressure vessel and divides it into the "clean" and "dirty" gas sides. Hot, particulate laden gas enters the pressure vessel and passes through the filter element collecting solids as a cake on the surface of the filter. The filtered gas flows into the plenum pipes and exits to the clean side of the main tubesheet structure. The ash collected on the short side channels of the cross flow filter elements is removed by reverse pulse jet cleaning and falls into the ash collection system attached to the bottom of the pressure vessel housing.

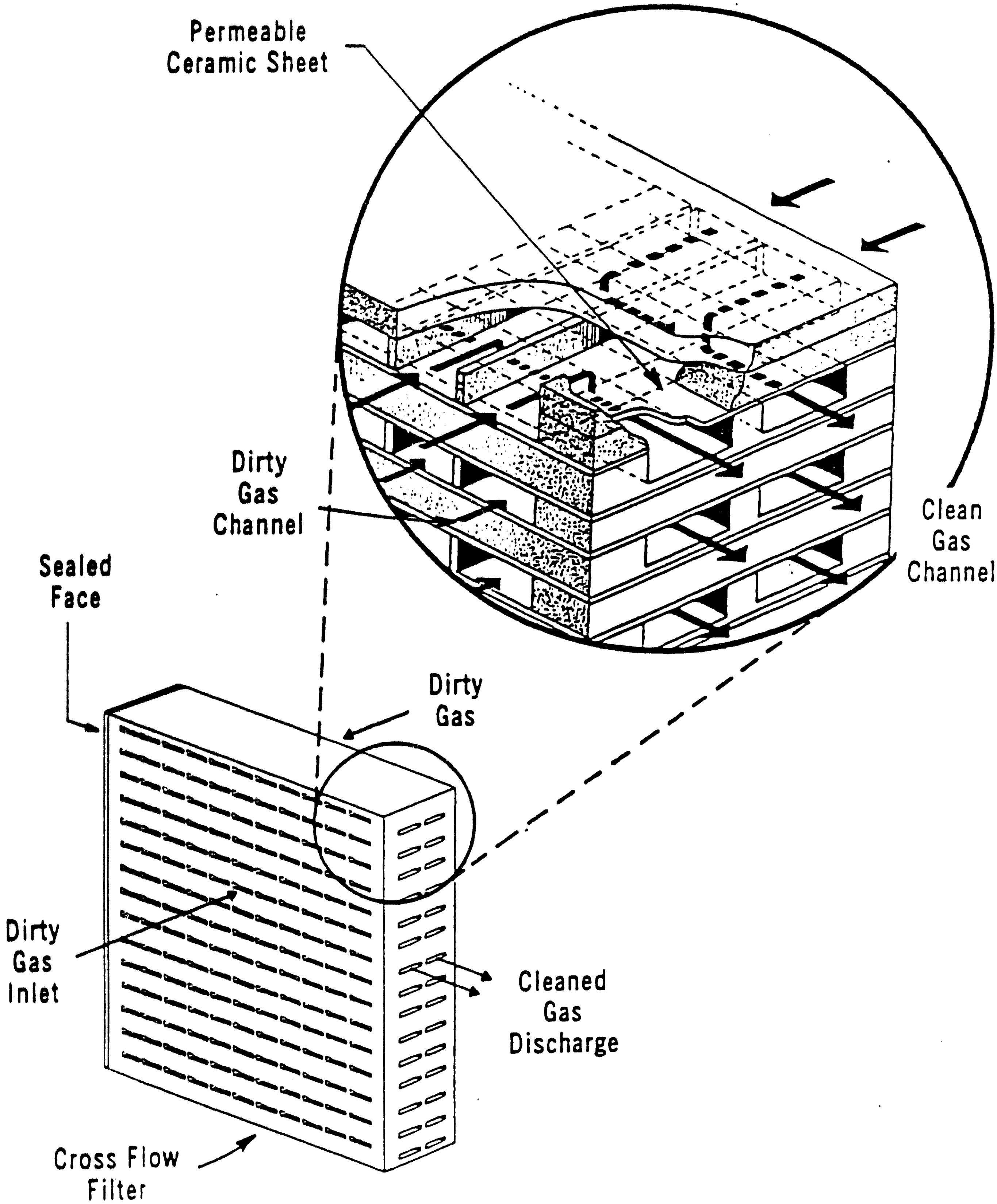

Figure 1.2 - Schematic Representation of Cross Flow Filter

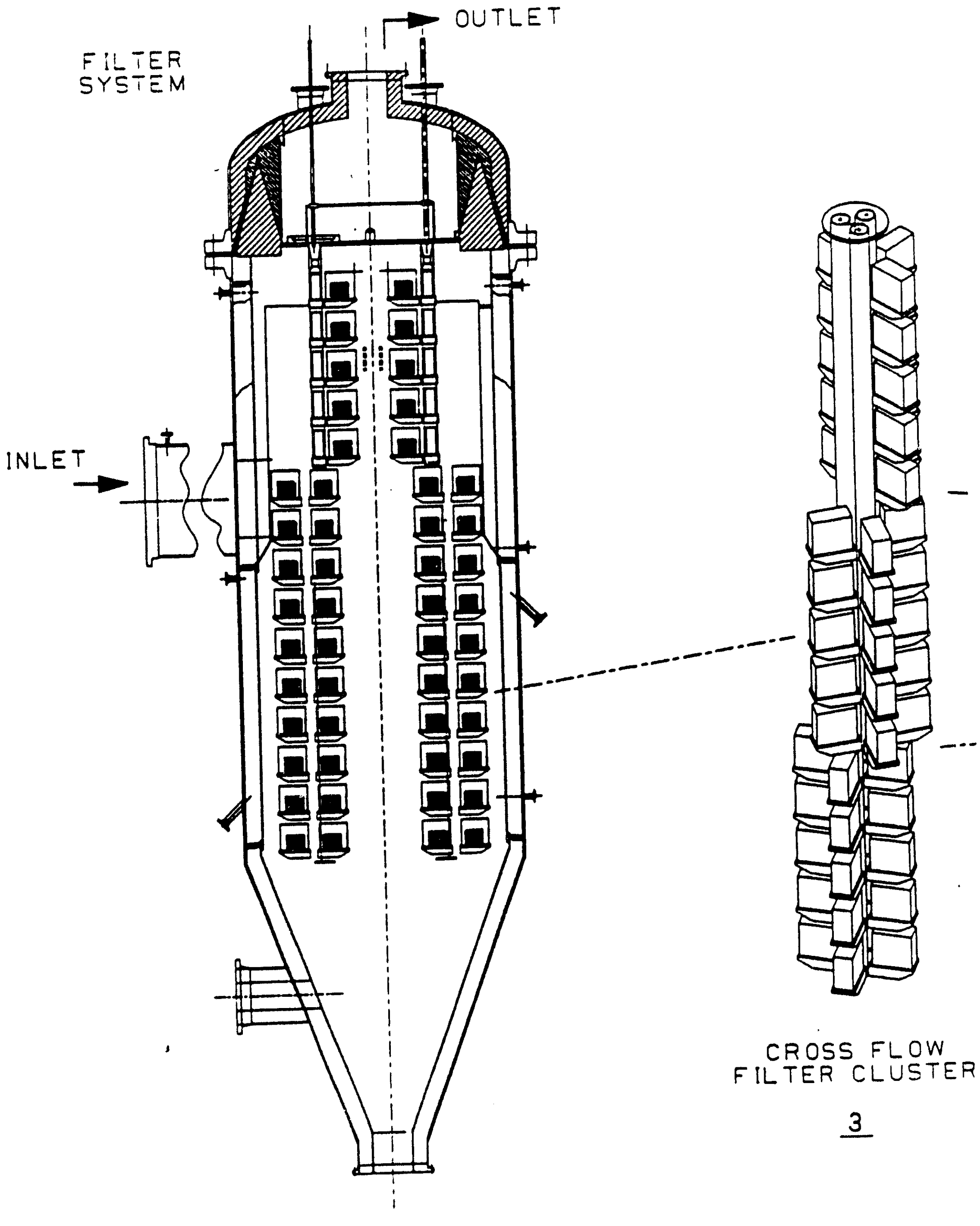

Figure 1.3 - Westinghouse Cross Flow Filter System Concept

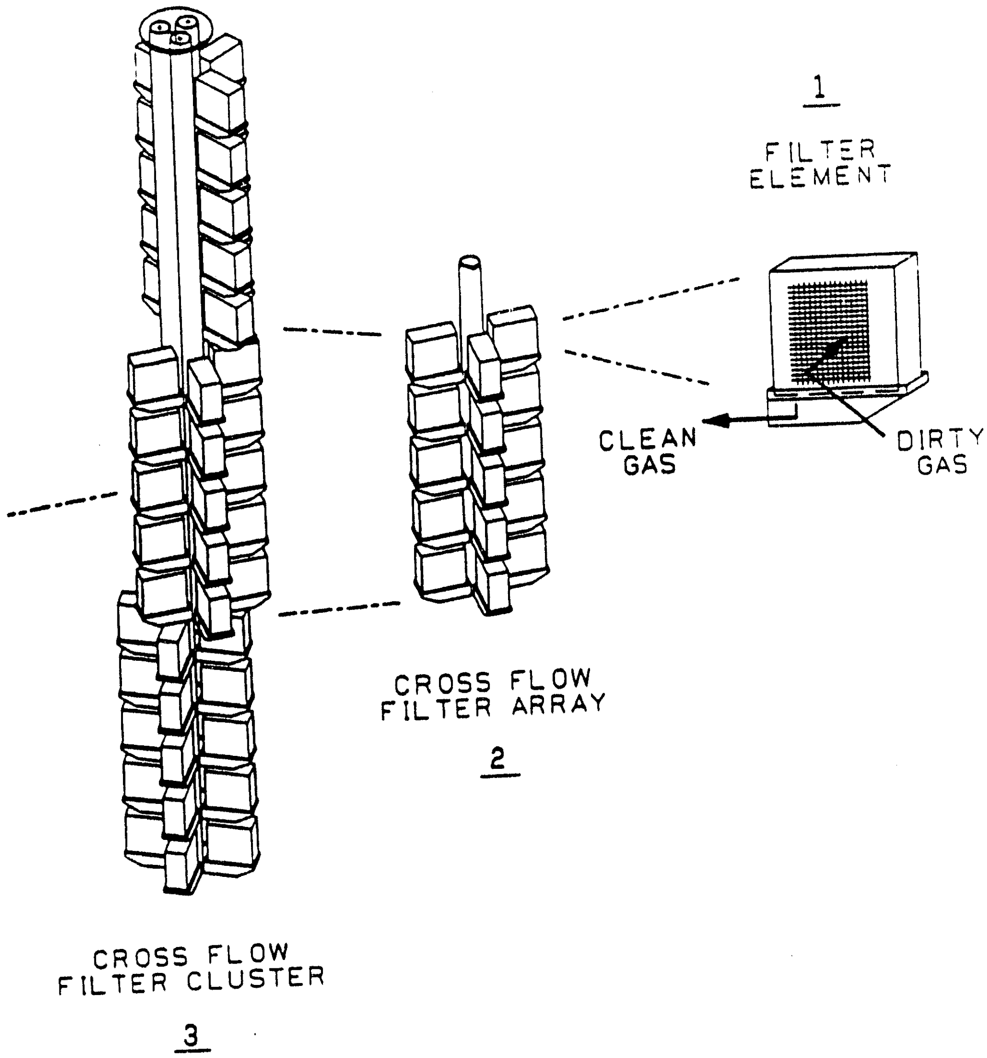

Figure 1.4 - Westinghouse Concept for Constructing Filter System from Single Cross Flow Filter Elements

The cluster concept provides a modular approach to scaleup and permits maintenance and replacement of individual filter elements. A very similar design for the candle system has also been developed, Figure 1.5. Candle and cross flow clusters are interchangeable in the Westinghouse scheme.

The major attributes of the cross flow filter concept are its absolute filtration characteristics on ash material and capability to be operated at relatively high flow capacity (high face velocity) with low pressure drop. Since each of the filter plates represent a filter surface, the cross flow configuration provides very high filter surface area to volume characteristic and the potential to be compact and economic. Candle filter technology provides similar performance but somewhat lower surface area to volume packaging characteristics.

1.2 CROSS FLOW FILTER DEVELOPMENT

Westinghouse has focused on cross flow filters that have been fabricated from an alumina/mullite ($Al_2O_3/3Al_2O_3 \cdot 2SiO_2$)-based material. Development efforts have included scale-up of the filter elements from a 15.24 x 15.24 x 5.08 cm (6 x 6 x 2 inch) configuration, with rib-to-plate bonds, to a 30.48 x 30.48 x 10.16 cm (12 x 12 x 4 inch) body that incorporates a mid-ribbed bond (MRB) configuration. The MRB provides a symmetric plate design that has improved manufacturing characteristics, and eliminates high stress sharp channel corners by moving the bond to a low stress region.[2]

Modifications have also been made in the fabrication and manufacturing of the cross flow filter elements to improve retention of the base material strength and porosity properties while maintaining a crack-free, dimensionally stable, plate assembly with improved bond strength.[3] An additional feature which has been incorporated into the cross flow filter design is the inclusion of a radiused flange section which eliminates stress risers, and provides a more delamination-resistant filter body.

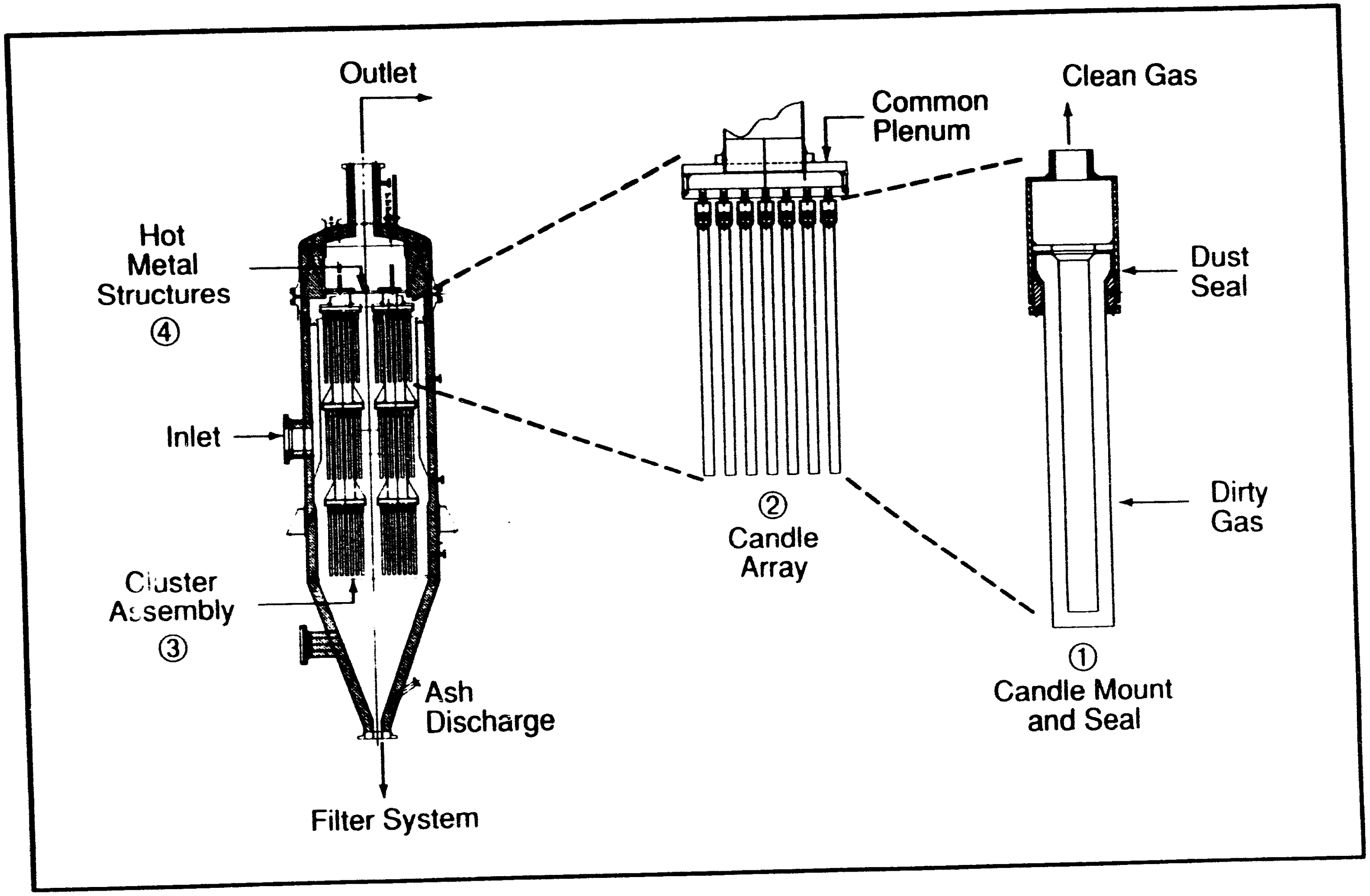

Figure 1.5 - Hot Gas Cleaning Systems - Westinghouse Candle Filter System

The development of the cross flow filter has evolved through the stages of initial exploratory studies to proof-of-concept test at various bench-scale gasification and combustion facilities. Initial exploratory st .ies were focused on subscale filter element size (15.2 x 15.2 x 5.1 cm - 6 x 6 x 2 inch) tested in a bench-scale PFBC simulator and small fluid bed PFBC and gasifier facility.[4,5] This work focused on evaluating the basic filtration properties of the cross flow geometry and methods to seal and mount the filter in high temperature gas streams. These studies demonstrated the technical and economic potential of the unique cross flow geometry. Bench-scale test results showed that 1) the conditioned filter resistance was low compared to other types of filter and inertial devices, 2) simple pulse-jet methods could be used to clean the filters, and 3) essentially absolute filtration on coal ash and char materials could be achieved. Delamination of the filter at the bonded joints was identified as a manufacturing development issue.

Initial scaleup of the filter element to commercial size (30.5 x 30.5 x 10.2 cm - 12 x 12 x 4 inch) and its testing was also accomplished. This testing included a very successful, 160 hour operation of an eight (8) element, four (4) module system under simulated PFBC conditions of the mid-rib bond cross flow filter design. The filters were flange mounted and compressively braced, an approach implemented to mitigate filter delamination. Post test inspection revealed that six (6) of the commercial scale filter elements had no structural damage but two (2) of the elements had suffered hairline delaminations that had apparently initiated from the mounting flange. Even with the delaminations, excellent filter system performance was achieved with outlet dust loadings ranging between 2 to 6 ppm.[5]

Following the subscale and initial full scale element testing summarized above, program emphasis was focused on integrated testing on pilot scale PFBC and gasification facilities. At the New York University PFBC facility located at the Antonio Ferri Laboratory in Westbury, New York, a Westinghouse cross flow filter system was integrated into the test facility and operated in two separate 50 hour test programs.[6] The filter unit consisted of five filter modules, each containing three filter elements, fifteen total elements (30.5 x 30.5 x 10 cm - 12 x 12 x 4 inch).

During the initial 50 hour test segment, operating at temperatures between 1300 and 1500°F (705 and 815°C), system pressure of 120 psia (8.3 bar), and filter face velocity of 5.2 ft/min (2.6 cm/sec) stable baseline operating pressure drop of 35 in wg (8.68 kPa) was achieved with simple pulse jet cleaning. Inlet PFBC dust loadings of 250 to 1056 ppm were reduced to outlet dust loadings of 2.9 to 8.9 ppm. Outlet cascade impactor dust sampling was also obtained that showed both loading and size distribution fall within published gas turbine tolerance requirements, Figure 1.6.

In the second 50 hour test run, the filter was operated at a 10 ft/min (5.1 cm/s), higher outlet dust loadings (up to 103 ppm) were encountered due to dust seal leaks that occurred after three of the five pulse valves malfunctioned and other facility operating problems were encountered. Inspection of the test unit showed that five of the fifteen filters had experienced hairline delamination cracks although none appeared to present a significant dust leak path. This testing also demonstrated that the 3M INTERAM® brand mat material used for gasketing was not sufficiently tolerant to temperature transients and susceptible to eventual eroding from between the filter and its mount.

Although cross flow filter field test programs provide opportunity for integrated operation in gas environments typical of large scale or commercial systems, they generally do not afford long operating periods. Also, filter test time is often compromised because of operational issues associated with the gasifier, combustor or some

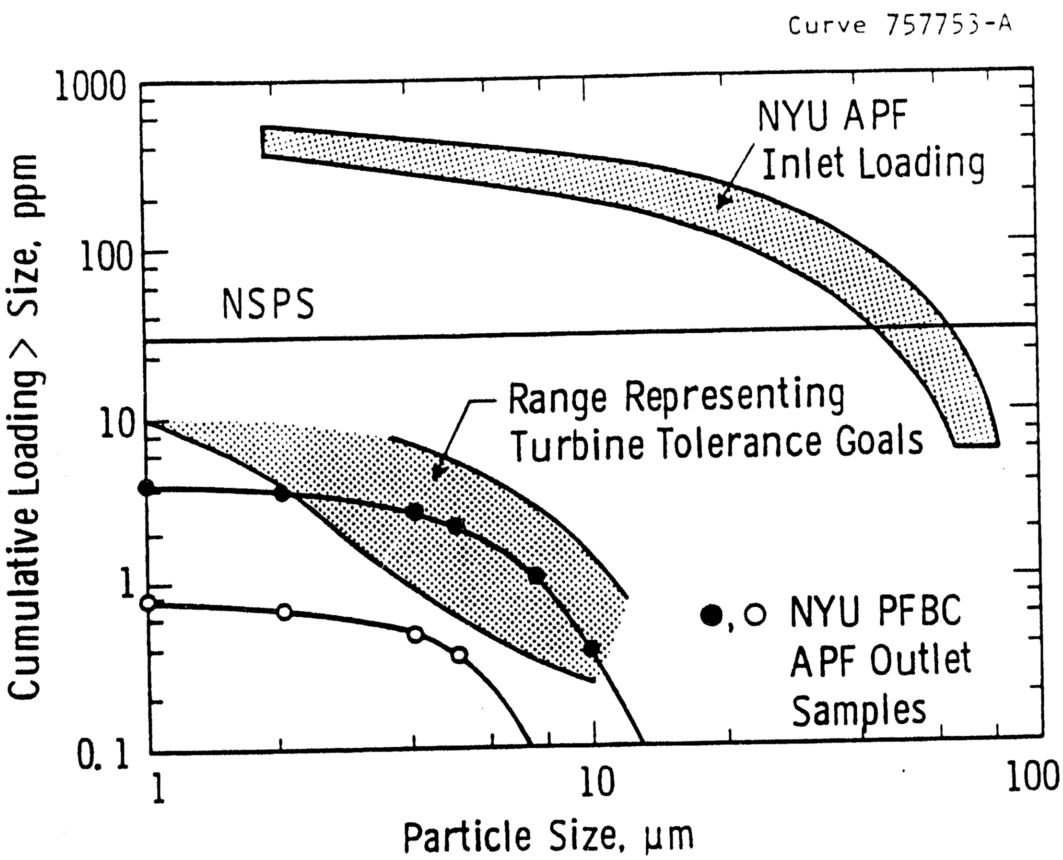

Figure 1.6 - Data Comparing Outlet Particle Size Distribution with Turbine Tolerance Goals

other ancillary equipment or because of other test priorities. The Long Term Durability Testing of Ceramic Cross Flow Filter program (DE-AC21-87MC24022) was designed to provide dedicated filter test operations for test periods significantly longer than current pilot plant test programs.[7]

In this program, two dedicated HTHP filter test facilities (Figures 1.7) were constructed and operated. These test facilities are intended to provide simulated HTHP gas environments for evaluating the filter using ash materials from PFBC and coal gasification facilities. The PFBC simulator facility is designed for a gas flow up to 680 kg/hr (1500 lb/hr), combusting methane to provide the thermal input. A gravimetric dust feeder and a pneumatic transport line are used to re-entrain the ash. The second test system is a closed loop that is electrically heated and designed to provide a HTHP reducing or inert gas environment, permitting the feeding of char/ash material. In this facility, up to 680 kg/hr (1500 lb/hr) of gas flow is recirculated using a specially designed HTHP eductor. Approximately 10 percent of the gas is used as the motive flow for the eductor.

Both test loops have on-line ash collection and removal capability that permit round-the-clock operation over extended test periods (i.e., 100 hours or more). These facilities are operated over a wide range of flow, pressure and temperature conditions. Both test loops are instrumented to provide filter operating and system performance data, including a computer-based data acquisition system.

The program provided for 3000 hours of testing under PFBC conditions and 2000 hours under simulated gasification conditions. The goal was to achieve this testing utilizing a single set of cross flow filter elements, respectively. For the simulated gasifier testing utilizing a char feed, this goal was achieved. In the simulated PFBC testing a total of 3080 test hours was accomplished but events precluded the use of a single filter set. Two filters achieved over 1300 hours,

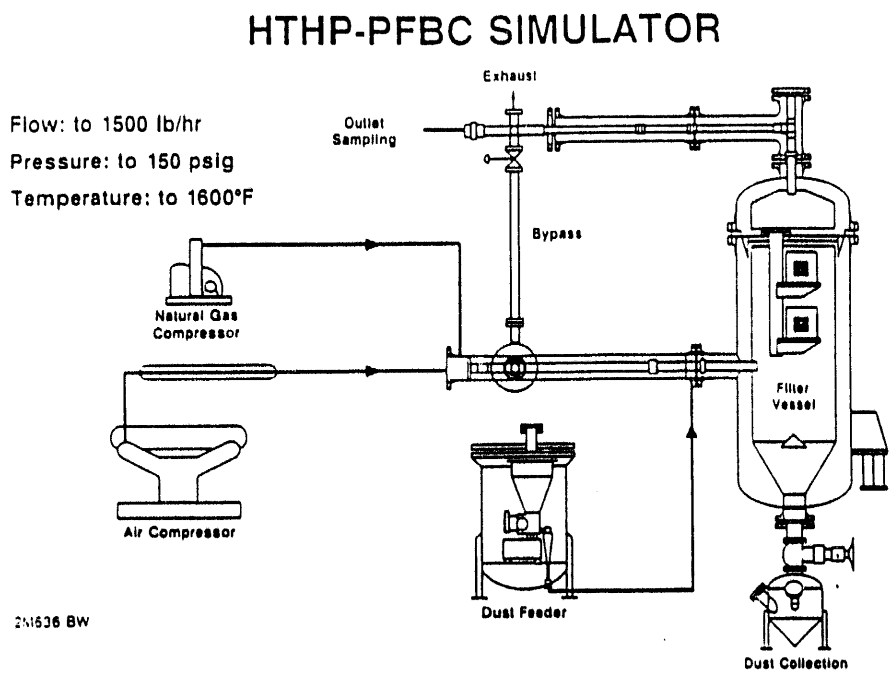

Figure 1.7a - Schematic of Westinghouse PFBC Simulator Test Loop

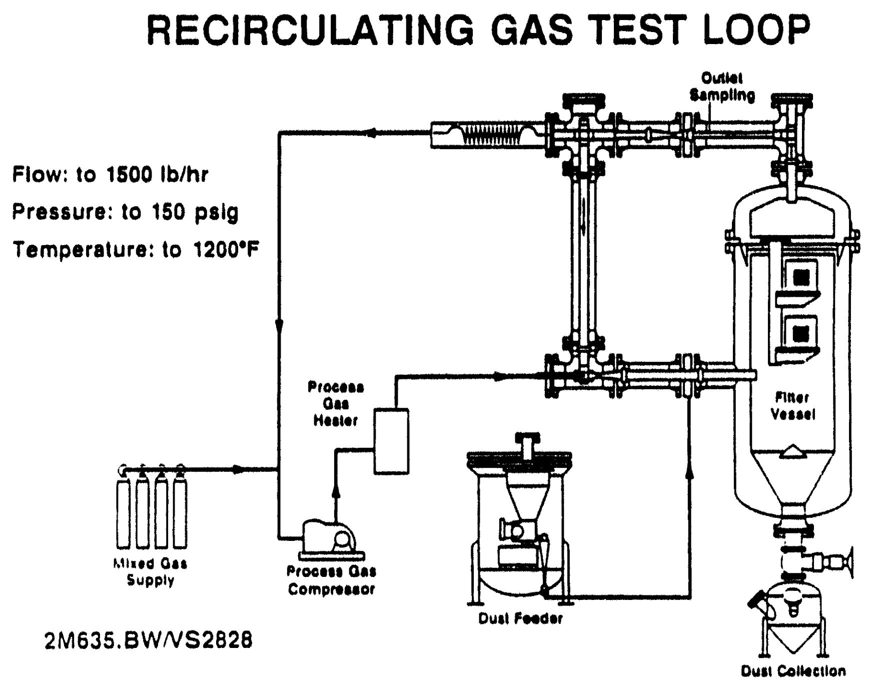

Figure 1.7b - Schematic of the Westinghouse Gasifier Simulator Test Loop

three other filters 1000 hours and one filter that was also utilized in the gasifier simulator testing had an accumulated exposure of over 2500 hours. Table 1.1 provides a summary of results from these extended testing periods.

Operating characteristics of the cross flow filter were investigated in the long term test runs. In the 1300 hour PFBC testing, the filters were subjected to over 2060 pulse cleaning cycles. The cross flow filters exposed to simulated PFBC conditions for 1100 hours were also exposed to simulated turbine trip and accelerated pulse cleaning cycles. In both the PFBC and simulated gasifier test loops, effective, on-line filter cleaning was demonstrated. Baseline filter system pressure drops were well below program criteria (<100 in wg, 25 kPa).

An important focus of the extended testing of the current program was the evaluation of filter system component durability. Test experience has demonstrated that the cross flow filter is basically an absolute filter on ash type material provided component integrity is maintained. In the PFBC simulator testing both filter element and gasket failures occurred that compromised filter performance. Although no gasket or filter failures were experienced in the gasifier simulator testing, ongoing cross flow filter testing in gasifier pilot plant systems had experienced such failures.[8] In the early phases of the PFBC simulator testing an improved design of the ceramic mat gasket was developed and backfitted to both the PFBC simulator testing and ongoing gasifier pilot plant filter tests. Also, this improved gasket design was implemented into the testing in the gasifier simulator tests. In all subsequent testing, gasket failures have been eliminated utilizing this modified gasket design.

Cross flow filter element failures under service condition can be characterized as one or more of the following types: debonding of plate seams, delaminations (hairline cracks that follow plate seams), by cracks that propagate across the plate seams and cracks that occur along the mounting flange. Improvements in cross flow filter manufacturing have substantially improved filter element integrity as demonstrated by the durability of the cross flow filters used in the extended simulator test periods.

Table 1.1 - Summary of Cross Flow Filter Performance in Long Term Durability Simulator Testing

	PFBC Ash Test Loop		Gasifier Char Test Loop
	Test Module #1	Test Module #2	Test Module #1
No. of Filters	2	4	2
Operating Conditions			
Temperature, °F	1550	1550	350-1200
Pressure, psia	85	85	85
Inlet Dust Loading, ppm	1000	1000	1000-1500
Face Velocity, ft/min	6 to 10	3 to 5	2-5
Cumulative Hrs.	1300	1100 2400	2000
Performance			
Avg. Outlet Loading, ppm	<1	<1	<1
Baseline Δp, in wg	8-20	4-10	1-4
Comments	Flange Failure	New Mount	No Failures

Uncontrolled plant thermal transients represent the major concern regarding delamination and filter plate cracking. Simulator testing has demonstrated that the cross flow filter can endure controlled plant transients typical of PFBC plant startup and turbine trip. A deficiency in the filter mount design that was not apparent from earlier short term tests caused flange cracking terminating the 1300 hour test run in the PFBC simulator testing that was not apparent from earlier short term tests. A redesign of the filter mount was made to eliminate the root cause of the observed failure; (nonuniform loading of the flange and the buildup of dust fines in crevices between the mount and filter flange). This design was implemented in subsequent PFBC simulator and Texaco gasifier pilot plant testing. Although testing has been limited (1000 to 2000 hours), no further failures in the filter flange were experienced in the Long Term Durability program.

1.3 REFERENCES

1. "Technical and Economic Evaluation of Ten High Temperature, High Pressure Particulate Cleanup Systems for Pressurized Fluidized Bed Combustion," DOE/MC19196-1654, July 1984.

2. Ciliberti, D. F., T. E. Lippert, and R. N. Kleiner, "A Mechanical Analysis of a Cross Flow Filter," Proceedings of the Seventh Annual Gasification and Gas Stream Cleanup Systems Contractors' Review Meeting, Vol. 1, DOE/METC 87/6079, pp. 308-320, 1987.

3. Lippert, T. E. and D. M. Bachovchin, "Mechanical Analysis of a Ceramic Cross Flow Filter," Proceedings of Advanced Research and Technology Development (AR&TD), Direct Utilization and Instrumentation and Diagnostics Contractors' Review Meeting, Sponsored by PETC and METC, U.S. DOE, Pittsburgh, PA, pp. 164-171, 1988.

4. Ciliberti, D. F., "Hot Gas Cleanup Using Ceramic Cross Flow Membrane Filters," Final Report DOE Contract DE-AC21-79ET15491, DOE/ET/15491-1565, December 1983.

5. Lippert, T. E. et al., "Performance Evaluation of a Ceramic Cross Flow Filter on a Bench-Scale Coal Gasifier," Final Report DOE/MC/21338-2749, September 1989.

6. Lippert, T. E., G. B. Haldipur, E. E. Smeltzer, and J. H. Meyer, "Performance Evaluation of a Cross Flow Filter on a Subpilot-Scale Pressurized Fluid Bed Coal Combustor," Final Report, Westinghouse Electric Corporation, DOE METC Contract No. DE-AC21-85MC22136, 1989.

7. Lippert, T.E., et al., "Long Term Durability Testing of Ceramic Cross Flow Filter," Final Report, Westinghouse Electric Corporation. DOE METC Contract No. DE-AC21-87MC24022 - pending.

8. Haldipur, G. B., et al., 1990, "Sub-Pilot Scale Gasifier Evaluation of Ceramic Cross Flow Filters," Proceedings of the Tenth Annual Gasification and Gas Streams Cleanup Systems Contractors Meeting, p. 73-82. DOE/METC-90/6115.

2. DESCRIPTION OF TEST FACILITIES

2.1 TEXACO PROCESS - ENTRAINED GASIFIER PILOT PLANT FACILITY

The Westinghouse Science and Technology Center (STC) with Texaco conducted a test program on a hot gas filter system which was integrated with the Texaco entrained-bed, slagging gasifier located at Montebello Research Laboratories (MRL) in California. Figure 2.1 shows the schematic arrangement of the test facility. The filter system and fines collection hopper are situated between the radiant and convective syngas coolers. As shown in the process schematic, a coal slurry and oxidant (air or oxygen) flow cocurrently downward through the gasifier. The partial oxidation reactions and ash melting that occur in the gasifier are carried out at temperatures of 1205-1540°C (2200 to 2800°F), and at 350 psig. The bulk of the molten ash is quenched in a slag bath located directly below the gasifier and withdrawn as a slurry. The hot syngas with a small amount of entrained ash/char exits the gasifier, is cooled in the radiant syngas cooler to a nominal 540 to 815°C (1000 to 1500°F) and introduced into the filter system. For some testing, a precleaning cyclone was used to reduce the filter inlet loading caused by soot blowing operations in the radiant cooler. The filtered gas proceeds to the convective cooler (which also houses the sorbent beds used for external desulfurization testing) and is then flared at the exhaust stack. The filter protects the sorbent beds from ash plugging. The Texaco test program also included the use of in situ sorbents. As shown, these sorbents were injected either into the gasifier, via the coal slurry, or into the radiant upflow cooler as a separate slurry. The particulate matter carried into the filter system would vary depending upon the in situ desulfurization method and sorbent utilized.

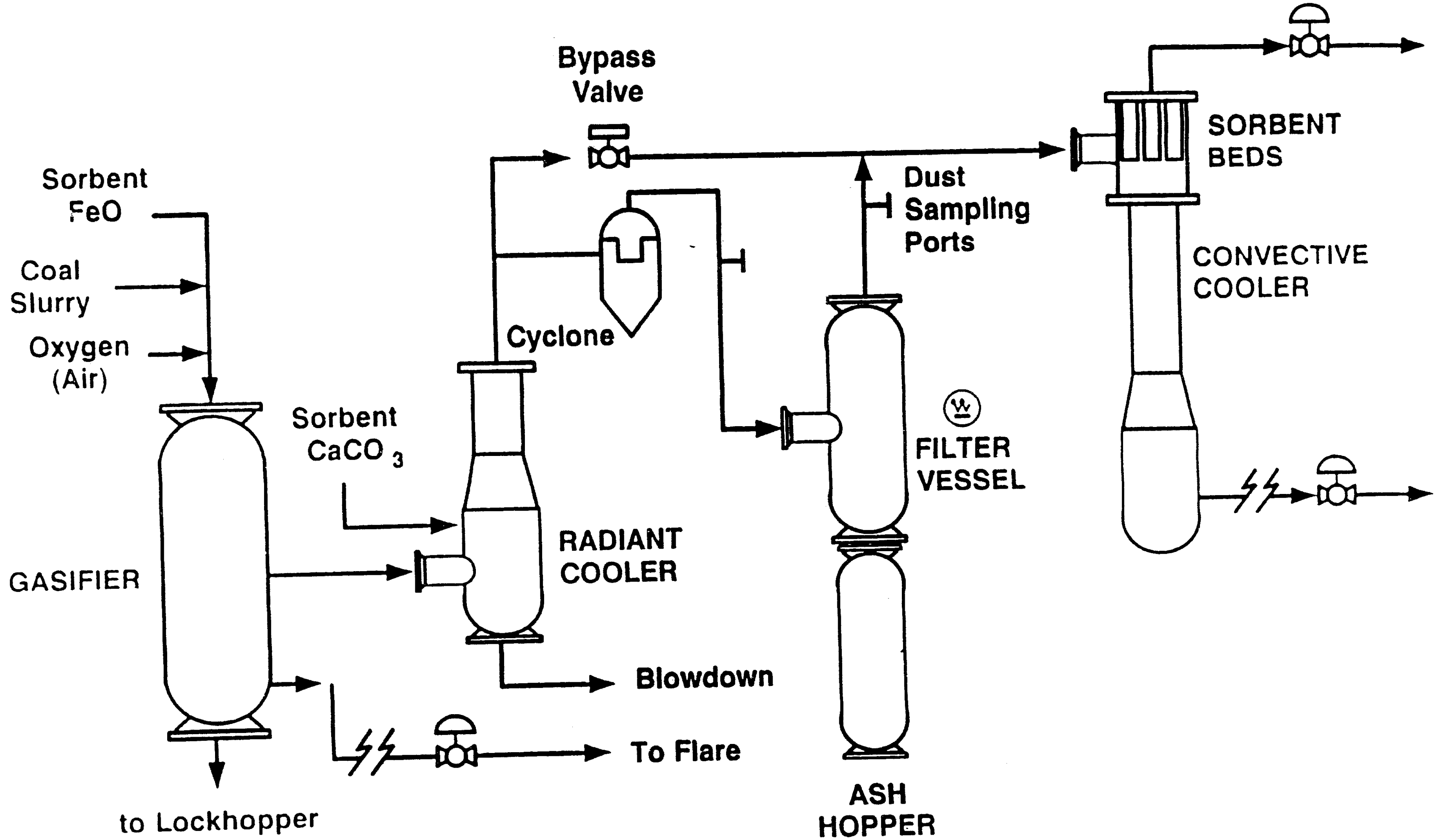

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Figure 2.1 - Schematic of Texaco Entrained Gasifier Facility with Westinghouse Hot Gas Filter

A bypass line was also provided around the filter unit to permit operation of the gasifier in the event of filter failure and to help mitigate operational variances, should they occur.

At the initiation of a test run, the main gasifier head flange is removed and an atmospheric preheat burner is bolted on the flange. The burner is ignited and a steam eductor is used to aspirate the exhaust gases from the burner through the entire process train, including the filter system. Upon achieving a predetermined temperature inside the gasifier, the atmospheric burner is removed and substituted with a special proprietary process burner in preparation for light off. After achieving coal ignition at atmospheric pressure, the system is ramped to process conditions by throttling the pressure control valve. Thereafter, the flow control valves are opened to direct hot fuel gases into the syngas coolers and the filter system.

Typically Pittsburgh No. 8 coal was used as the feed coal throughout the entire test program at the Texaco gasifier. Table 2.1 provides a composition of the syngas which was typically produced. Since testing of the Westinghouse cross flow filter system was carried out in conjunction with Texaco's desulfurization program with DOE, the concentration of hydrogen sulfide (H_2S) in the syngas most likely varied. When no sulfur sorbents were added to the feed slurry, the H_2S syngas concentration was estimated to be 0.5% (dry) during oxygen-blown gasification of Pittsburgh No. 8 coal. When sulfur sorbents were added to the coal feed slurry, the concentration of H_2S in the syngas was estimated to be as low as 0.06%.

The concentration of particulates released into the syngas stream varied with throughput and the condition of the slag knockout pot which was located between the gasifier and the radiant syngas cooler. During testing there was no means to vary or regulate the concentration of fines carryover. Less than 10% of the gasifier coal feed ash was expected to have been carried over as particulates in the syngas at the exit of the radiant cooler. This is roughly equivalent to 4,000 ppmw entering the filter vessel.

Table 2.1 - Summary of Texaco Entrained Gasifier Operating Conditions

General:

Pressure:	350 psig
Temperature:	1200-1550°F
Gas Flow Rate:	
Nominal	2500 lb/hr (100 acfm)
Maximum	4000 lb/hr (160 acfm)
Dust Loading:	< 400 ppmw
Moisture Content:	~ 12% (air blown)
	24% (oxygen blown)

Gas Composition (dry):

	O_2 Gasification (Vol%)	Air Gasification (Vol% Estimated)
H_2	35.6 to 37.4	12.0 to 16.0
CO	45.5 to 49.4	16.1 to 20.1
CO_2	12.2 to 16.3	3.4 to 7.5
CH_4	0.0 to 0.1	0.0 to 0.1
H_2S	0.0 to 0.6	0.0 to 0.3
N_2	0.4 to 0.5	60.0 to 64.0

Typically ash within the coal feed is melted in the gasifier and is quite fluid at high temperature. If entrained syngas particulates have inadequate time to cool during transport from the gasifier through the radiant cooler, the potential exists for carryover of "sticky" particulates which contact and adhere to the filter surface. Filter pore plugging and subsequent gas flow restriction could also result from contact with "sticky" ash particulates.

The temperature of the syngas at the inlet to the ceramic cross flow filter system is governed by the gasifier exit temperature, the syngas production rate, and the amount of cold recycled gas to the radiant syngas cooler. The highest temperature, which is obtained at the highest throughput with no recycle syngas, and with external sorbents is approximately 845°C (1550°F). Lower temperatures are obtained by reducing the throughput or by recycling cold syngas to the radiant cooler. Adding recycled syngas also reduces the moisture content and particulate concentration, while increasing the total syngas feed to the ceramic filter.

2.2 DESCRIPTION OF WESTINGHOUSE HOT GAS FILTER SYSTEM

Throughout the entire course of testing, the Westinghouse filter system was located between the radiant and convective syngas coolers in the Texaco pilot plant gasifier system. A full port bypass valve was provided across the filter system to divert the bulk of the gasifier exhaust gas directly to the convective cooler. A description of the Westinghouse filter unit, pulse cleaning, ash collection, instrumentation, and gas sampling systems are provided in the following sections.

2.2.1 Filter Unit

A schematic of the Westinghouse hot gas filtration unit is shown in Figure 2.2. The mechanical drawings and Process and Instrumentation Diagrams (P&ID's) are provided in Appendix A. The nominally 3.0-m (10-ft) high, 1.05-m (41.6-in) OD pressure vessel was constructed and

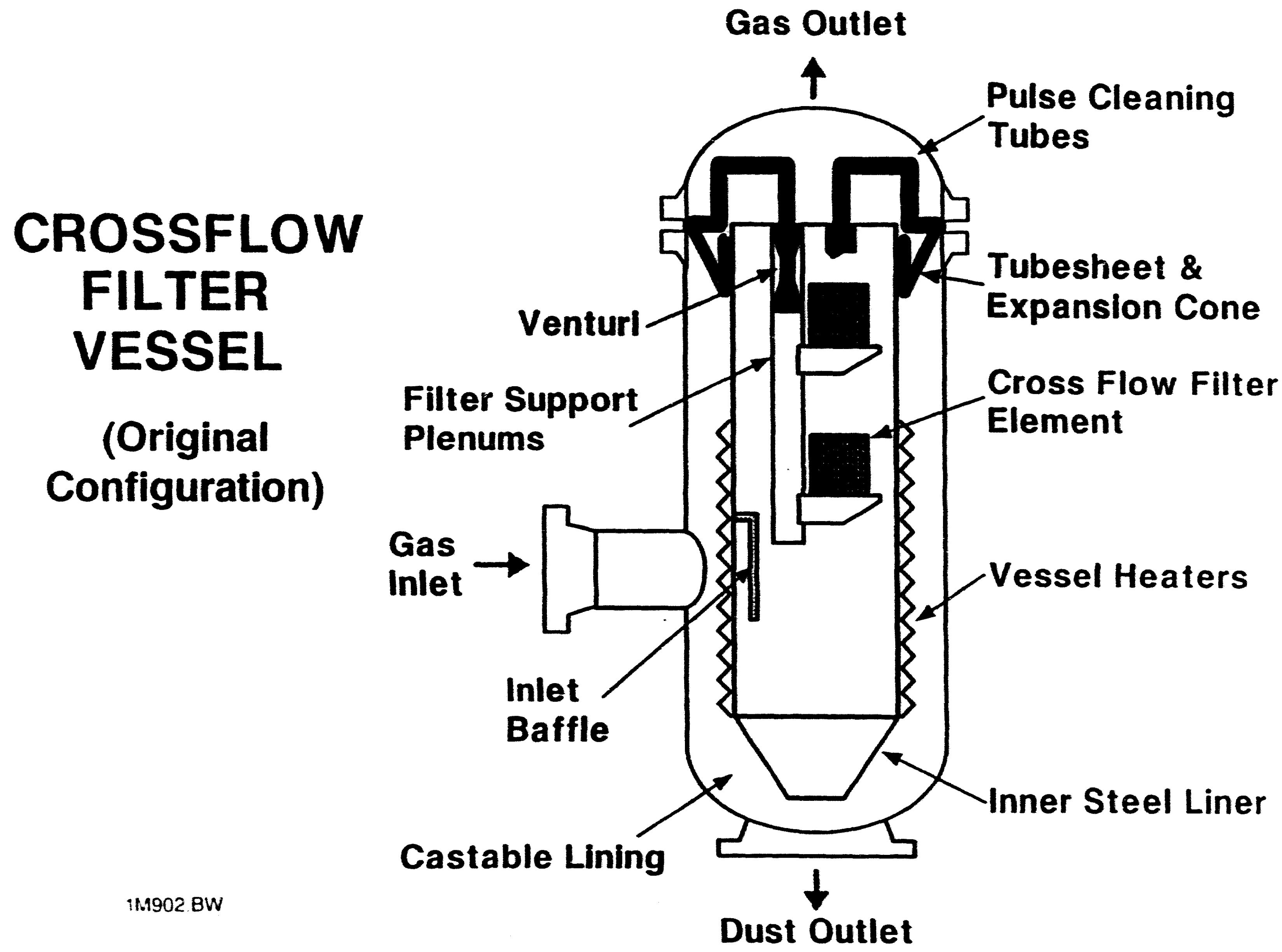

Figure 2.2 - Schematic of Westinghouse Hot Gas Filter Test Unit Using Ceramic Cross Flow Filters

rated at 450 psig at a 345°C (650°F) shell temperature as specified by ASME Section VIII requirements. The filter vessel was lined with 11.4-cm (4.5-in) of Harbison Walker Lightweight Castable 26 refractory. The vessel had 30.5-cm (12-in) 300 pound class flanged gas inlet and outlet nozzles with 10-cm (4-in) thick cast refractory lining. The gas inlet nozzle was placed below the level of the hanging filter modules to avoid direct impingement of incoming gas on the filter elements. The top gas outlet had a lined pipe tee, and was blind flanged at the top for additional access. The filter cake discharge at the bottom of the vessel had a 46-cm (18-in) 300 pound class flanged nozzle which joined the ash collection vessel that was provided by Texaco.

The filtration cavity in the vessel was enclosed within a 76.2-cm (30-in) diameter 316 stainless steel sheet liner. Incoloy-sheathed resistance heaters were provided for preheating the filter vessel during start-up, as well as for heating to keep the 316SS liner, and the dust that was in contact with the liner above the dew point.

Both the cross flow and candle filters were housed inside the 1.05-m (41.6-in) OD refractory and stainless steel sheet liner. During cross flow filter testing, either four or eight filter elements were mounted on two stainless steel plenums that were attached to a metal tubesheet. Alternately, nineteen candle filters were individually mounted from a single plenum which was directly attached to a metal tubesheet. Typically the cross flow and candle filter tubesheets were constructed out of 310 stainless steel with conical sections that served to minimize thermal and mechanical stress, and distortion during high temperature filter operation. The tubesheet was clamped between the full diameter vessel flanges and was pressure sealed using Flexitallic gaskets.

Pulse cleaning tubes were directed through the tubesheet and oriented concentrically with either the cross flow or candle filter plenum. Each plenum is also equipped with a recessed venturi that facilitated eduction of hot fuel gas from the clean side of the vessel, thereby augmenting the intensity of the reverse pulse and minimizing the thermal shock to the filters. High pressure nitrogen gas was used during sequentially pulse cleaning events. The majority of the instrumentation leads also entered the pressure vessel through radial channels drilled through the tubesheet ring flange. Resistance heaters were strapped to the inside stainless steel liner of the filter vessel in order to provide filter preheat capabilities prior to gasifier operation. Following initial operation, these heaters failed and preheating of the filter unit was accomplished using the Texaco gasifier preheat system.

2.2.2 Pulse Cleaning System

The filter element pulse cleaning system P&ID is given in Appendix A (P&ID No. 6) and consisted of an external accumulator tank which was constructed from a 48 inch long piece of 10 inch pipe, with end caps, rated at 2200 psig at 100°F. Pulse cleaning gas was directed into a 2 inch nipple at the tank exit, and then into a 1 inch schedule 80 pipe. The pulse cleaning gas then entered a tee which acted as an elbow, and passed through four ball valves, and one solenoid valve. Following the valving, the gas contracted into a 1 x 3/4 inch NPT pipe reducer, and entered through a 0.875 inch diameter flange ring in the tubesheet. After passing through another 3/4 x 1 inch connector on the inside of the vessel, the gas was expanded into a 1 inch schedule 160 SS pipe inside the filter vessel. The thick walled pipe was needed to prevent blowback tube deflection, as a result of the high temperatures and occasional high pressures inside the pipe. Three elbows were used to form an expansion loop which terminated in a pipe nozzle over the clean-side plenum of each filter module.

During conduct of this program, the ceramic filter elements were pulse-cleaned using a high pressure (1500 to 2000 psig) nitrogen gas pulse. The typical length of a pulse during pulse cleaning was on the order of 0.25 seconds. Between blowback pulses the pressure drop increases across the filter as the dust cake builds. During filter operation the filters were cleaned on either a set trigger pressure drop, or time basis. The blowback sequence consisted of pulsing each filter plenum once. When two plenums were utilized, pulsing was sequential with several seconds separating delivery of the pulse gas to each filter plenum.

2.2.3 Ash Collection

A simple ash collection system was utilized that consisted of a catch pot that filled and was emptied following each test run, see Appendix A, P&ID No. 7. A nitrogen purge line was provided to prevent syngas condensation and assist ash removal, if required.

2.2.4 Instrumentation

System instrumentation included capability for the following control and measurement functions:

1. Filter System Pressure Drop (P&ID No. 2, Appendix A)
2. Heater Control System (P&ID No. 3, Appendix A)
3. Blowback Pulse Pressure System (P&ID No. 4, Appendix A
4. Filter Plenum Flow Systems (P&ID No. 5, Appendix A)
5. Filter Blowback System (P&ID No. 6, Appendix A)
6. Ash Collection Pot (P&ID No. 7, Appendix A)

All piping and instrumentation connections to the filter vessel, other than the heater connections, were made through the tubesheet flange ring, which rests between the lower vessel and the vessel head (P&ID No. 1, Appendix A).

The ceramic cross flow filter elements were pulse cleaned by high pressure nitrogen pulses. A differential pressure transmitter senses the pressure difference across the ceramic filters. Both sides of the transmitter were protected from the blowback pulse pressure rise by normally open solenoid valves which close during pulsing. The output signal was sent to the recorder, a digital panel meter, and a controller which indicated the blowback pulses. A manual control override was also provided. A nitrogen gas purge line was connected to the high side line and allows for periodic flushing of this line to remove ash that may have entered the line. In parallel with the differential pressure transmitter was a differential switch which was used as a protective device preset to the maximum allowable Δp (i.e., 5 psid). If the Δp reached this pressure, the switch alarm alerted the operators to energise a by-pass valve so that the main gas flow was redirected around the filter vessel.

Thermocouples were used to measure the temperature of the center section and expansion cone section of the tubesheet. These were provided for informational purposes only.

An internal electric heating system was used to maintain temperature in the filter vessel (P&ID No. 3). The heater control system consisted of a temperature controller and a thermocouple that sensed the temperature of the heating element. Thermocouples monitored the temperature of the vessel liner which was displayed on a panel readout.

The blowback pulse intensity measurement system provided the capability of measuring the dynamics of pressure rise in a filter plenum during a pulse (P&ID No. 4). The low side of the differential pressure transmitter was connected to the filter plenum via the tubesheet and the high side was connected to the dirty side of the filter vessel. The output from the low side of the differential pressure transmitter was sent to a high speed recorder. A nitrogen purge line was connected to the high side line in order to blow out any ash that may accumulate.

The filter plenum flow system allowed for the measurement of the filtered gas flow through each of the two filter plenums, so as to verify proper flow distribution (P&ID No. 5). This was accomplished by measuring the differential pressure across the venturi section. The pressure differential transmitter sensed this Δp, sending a signal to a multipoint recorder. The low side of this transmitter was connected to the venturi throat and the high side just upstream of the venturi contraction. The gas temperature was recorded at the outlet of the plenum which was then used to calculate the gas flow rates through both plenums. Normally the two open solenoid valves closed during the blowback pulse so as to protect the pressure differential transmitter.

In the filter blowback system, high pressure nitrogen gas from the plant supply line passed through the check valve and high pressure regulator, and pressurised the blowback pulse accumulator vessel (P&ID No. 6). The pressure vessel was fitted with a pressure safety valve, a valved vent, and a pressure gauge. A one inch supply line was instrumented with a local gauge and a pressure transmitter which sent an output signal to a panel mounted pressure indicator. This line fed two identical branches, one for each plenum. Each branch had a solenoid blowback valve. Each valve was positioned between a double block and bleed system consisting of one inch full-ported ball valves. The ball valves possessed electrical operators which opened just prior to blowback, and closed during normal operation. The solenoid valves were 110 V AC powered and were controlled automatically by a pressure controller, or operated in a manual mode. The blowback line terminated inside the filter vessel with the end of each pipe directing the pulse gas into the corresponding plenum venturi.

The ash vessel nitrogen purge system has been supplied in order to reduce the possibility of combustible gas accumulating in the ash collection pot (P&ID No. 7). The vessel was fitted at the bottom with a six inch ball valve, and a blind flange to allow for the periodic removal of ash. Nitrogen gas entered at a tapped flange at the connection of the ball valve and the vessel bottom, and flowed upward into the filter vessel to sweep out air and/or process gas.

2.2.5 Particle Sampling

Figure 2.3 shows a schematic of the particle sampling train used on both the inlet and outlet of the filter unit. A simple nitrogen-purged tubing probe was inserted into the flow path. The probe

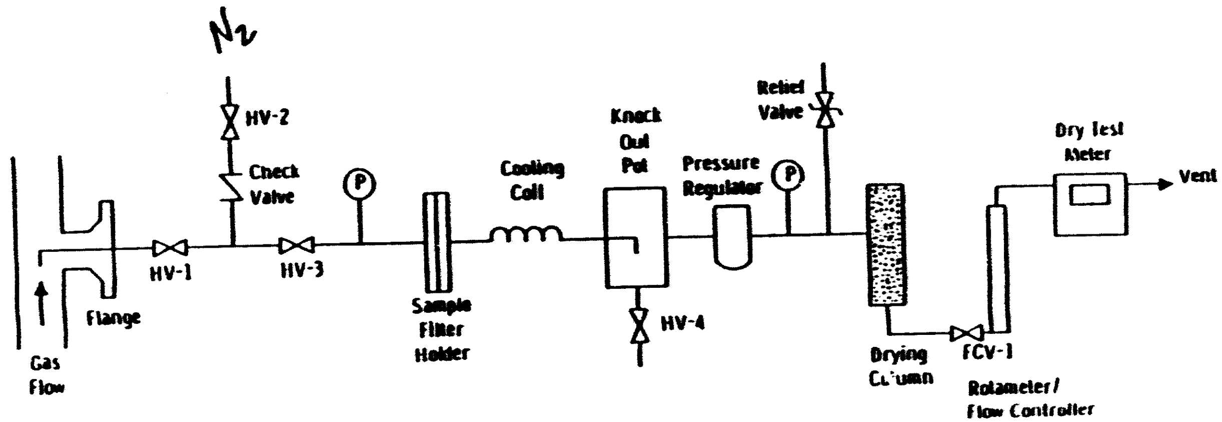

Figure 2.3 - Schematic of Particulate Sampling Train Used to Measure Inlet/Outlet Dust Loadings

was fitted with provisions for rotation into and out of the flow stream. Sampling flow was set with a valve that would allow the isokinetic sample to enter a filter holder that contained a ceramic fiber paper filter upon which a sample was collected. The exhaust gas was then dried in a knock-out pot and drierite bed, and finally the gas flowed through a rotometer and flow totalizer.

The entire assembly from the probe flange to the sample filter holder consisted of a straight line configuration, in order to minimize loss of dust at curves or bends. The entire length was wrapped with heating tape to prevent condensation before the sample filter holder.

Sampling was conducted in order to adequately monitor the performance of the cross flow filters, and to detect at least 1 ppmw dust in the outlet gas stream. Because of isokinetic flow, and the small nozzle size, the total amount of gas sampled was very small.

The inlet sampling system was virtually the same as the outlet gas stream supply system. Due to a much higher inlet dust load (i.e., nominally 4,000 ppmw), the sample duration was on the order of about five minutes, with samples taken periodically. If the process gas flow rate changed during sampling, the sampling line flow rate was reset so as to maintain isokinetic flow.

3. TEST PROGRAM AND RESULTS

The Westinghouse high temperature, high pressure (HTHP) filter system was operated on the Texaco gasification subpilot-scale plant in Montebello, CA. The filter unit was designed to operate at 350 psig pressure, with an internal temperature of about 1500°F, a volumetric flow range of 70-120 acfm, and a nominal mass loading of 4,000 ppmw. Eleven test runs, beginning in April of 1989 and concluding in August 1992, were made that included seven tests using cross flow filters and four tests using ceramic candles. The candle filters were tested to provide data on an alternative geometry, providing a basis to better assess the performance and operating characteristics that may be unique to the cross flow geometry. Tables 3.1 and 3.2 provide overall operating summaries of the filter test runs. All testing utilized a Pittsburgh No. 8 coal with the gasifier being either oxygen or air blown. As indicated, various desulfurization schemes were used. Section 2 provided nominal syngas compositions for the various gasifier operating conditions. This section describes each of the HTHP filtration tests that were performed by Westinghouse, using either a cross flow or candle filter configuration.

For each test run, the pressure drop characteristics of the filter unit was monitored and recorded. Appendix C provides data from two test runs (Run 6 and Run 10) that show the filter pressure drop characteristics typifying the filter operation in the subpilot scale entrained gasifier facility. Run 6 corresponds to the cross flow filter testing, while Run 10 shows candle filter data. Varying process gas conditions, uncertainty in actual filter inlet loading, and the relatively short cleaning cycles have complicated the utilization of these pressure drop traces as a reliable tool to interpret filter performance or identify abnormal operation. For example, damage to or

Table 3.1 - Westinghouse Filter Operating Summary

Test	Filter	Date	Hours	Startups	Oxidant	Additive	Pre-Cyclone
1	Cross Flow	4/89	48	1	O_2	None	No
2	Cross Flow	7/89	35	1	Air	None	No
3	Cross Flow	7/89	29	2	Air	None	No
4	Cross Flow	8/89	103	1	Air	FeO_x Internal	No
5	Cross Flow	11/89	65	3	Air	$CaCO_3$ External	yes
6	Cross Flow	1/91	42	3	O_2	None	Yes
7	Cross Flow	5/91	60	3	O_2	FeO_x-$CaCO_3$ Internal	No
8	Candle	9/91	62	2	O_2	None	No
9	Candle	11/91	34	2	O_2	None	No
10	Candle	12/91	89	5	O_2	None	No
11	Candle	7-8/92	101	8	O_2	None	No

Table 3.2 - Westinghouse Filter Process Data Summary

Test	Filter	Date	Temp (°F)	Inlet Loading (ppmw	Gas Flow (SCFM)	Notes
1	Cross Flow	4/89	1000	2000-10000	400-940	310 pounds of solids collected from catch-pot.
2	Cross Flow	7/89	1250	250-1220	290-730	34 pounds of solids collected from catch-pot.
3	Cross Flow	7/89	1300	270-22500	180-640	
4	Cross Flow	8/89	1300	280-2900	210-640	64 pounds of solids collected from catch-pot. Leak developed; one element was blown off seat and some filter element holding rods were missing. While filter was operating; outlet alkali concentration 10-50 wppb; inlet alkali 1-100 wppm.
5	Cross Flow	11/89	1400	650-12350	140-600	Cycle time dropped below 1 minute without dolomite injection. During dolomite injection cycle time was 15-20 minutes.
6	Cross Flow	1/91	1200	1170-1934	450-680	100 gallons of water taken from filter catch-pot after shutdown. 150 pounds of solids collected from the catch-pot.
7	Cross Flow	5/91	1400	1640	270-600	Rapid depressurization upstream of filters at shutdown; all elements were broken.
8	Candle	9/91	1300	1076-1873	380-630	84 pounds of solids collected from catch-pot.
9	Candle	11/91	1300	768-2525	380-660	52 pounds of solids collected from catch-pot.
10	Candle	12/91	1300	NA	340-580	
11	Candle	7-8/92	1500	NA		112 pounds of solids collected from catch-pot.

failure of the filter elements could not, in general, be identified or correlated to any change in the characteristic features of the system pressure drop.

3.1 FILTER SYSTEM COMMISSIONING TEST - CROSS FLOW

A commissioning test (Test No. 1) was conducted on the Westinghouse cross flow filter system over a four day period in April 1989. Two hot gas filter plenums were utilized in the commissioning effort. Each plenum contained two 12 x 12 x 4 inch alumina/mullite cross flow filter elements. During the commissioning test, the Texaco gasifier was operated in an oxygen-blown mode using a feed source slurry of Pittsburgh No. 8 coal and external sorbent beds for sulfur removal. Precleaning cyclones were not utilized during this phase of testing.

The four cross flow filters were operated over a temperature range of 790° to 1020°F, with a volumetric gas flow rate of 47 to 110 acfm. Four steady state test periods were identified for filter performance characterization and solids sampling system shakedown. The hot gas filter system was successfully operated for the planned 48 hours. The operational performance of the filter system, the pulse cleaning subsystem, and the inlet and outlet isokinetic sampling loops were assessed during this phase of testing. Table 3.3 summarizes the filter performance data for various steady state test periods.

During the commissioning test, the cross flow filter elements were periodically reverse pulse cleaned for a total of 270 pulses. During the initial 21 hours of filter operation, the system was pulse cleaned at a trigger pressure drop of 50 inches of water using tank pressures in the range of 850 to 940 psig. The time between filter pulse cleaning events ranged between 10 to 15 minutes during this test period, Figure 3.1, Set Point 3. For the balance of the commissioning test, the pulse tank pressure was increased to 1100 psig. At the higher syngas flows (95-110 acfm), higher trigger and baseline pressure drops were experienced. Pulse cleaning frequency also increased, ranging between 3 to 6 minute intervals, Figure 3.1, Set Point 6. Although

Table 3.3 - Nominal Filter Performance Data, April 1989 Texaco Test

Set Point	Hours at Set Point	Temp. °F	Gas Flow SCFH	Gas Flow ACFM	Pressure Drop in wg Trigger	Pressure Drop in wg Baseline	Dust Loadings Inlet ppm	Dust Loadings Outlet ppm
1	3.5	1016	30770	66	50	8	9109**	
2	3.5	876	16120	31	38-50	5		
3	13	790-845	40240*	76	50-70	13-20	2118	2.2 6.2
4	2.5	926	47570*	95	80-90	26		2.2
5	7	990	52700*	110	90	32-35	2646	
6	14.5	934-975	48300*	98	95	30-33	6752*** 1931 2490	3.9 2.1 4.0

* Includes 8000 SCFH cold recycle gas leak from soot blower.
** Gasifier operation not stabilized, possibly low carbon conversion
*** During soot blowing operation

Curve 784372-AF7

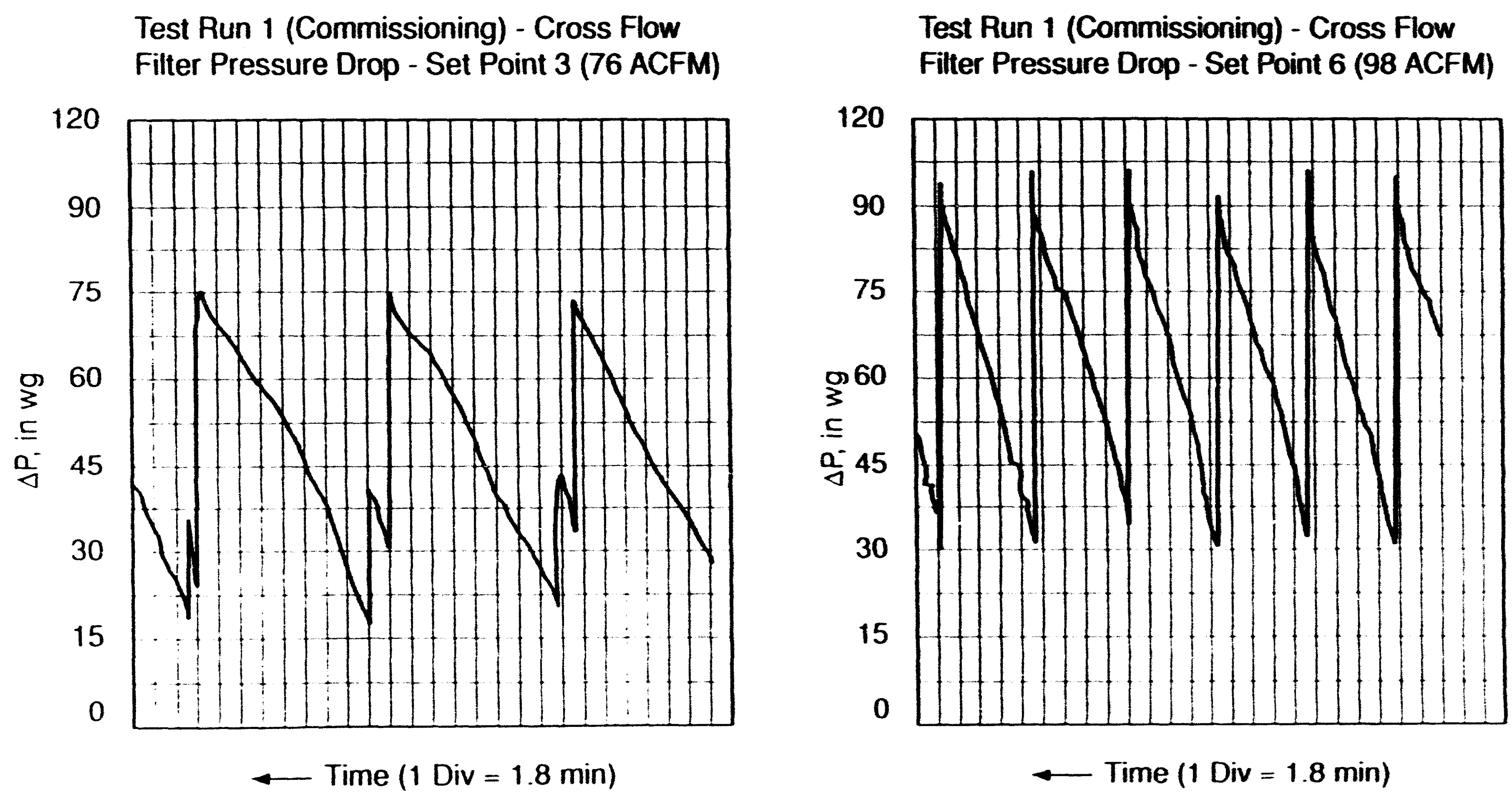

Figure 3.1 - Typical Cross Flow Filter Pressure Drop Characteristics During Steady State Operation (Commissioning Test Run)

stable baseline pressure drops were achieved in this testing, the pressure drop levels were higher and cleaning cycles more frequent than initially predicted. These aspects of the filter operation are reviewed and discussed in Section 4.

The inlet and outlet isokinetic sampling systems operated successfully during the commissioning test, and a total of six sets of samples were obtained. The overall operational performance of the sampling system was judged to be satisfactory, gas flow rates were closely controlled, and the samples were uniformly dry. The inlet mass loading varied between 1,930 and 9,110 ppm, while the outlet mass loading varied between 2.1 and 6.2 ppm, Table 3.3. These loadings are significantly below the NSPS limits for gasifier combined cycle power plants, and well below the gas cleanliness requirements for sorbent bed operation.

Inspection of the dust hopper after completion of the commissioning test indicated that approximately 310 lbs of fines had been collected, which was consistent with the nominal mass balance during gasifier and filter system operation. A small sample of collected ash was sent to Southern Research Institute for characterization. Results of this laboratory analysis are given in Appendix B and discussed in Section 4. A borescope inspection of the clean-side internal surface of each filter plenum showed no evidence of cross flow filter delamination or dust seal leakage. Based on this inspection, it was concluded that the filter unit did not need to be disassembled and that plans for the next test period could proceed.

3.2 HTHP FILTRATION UNDER AIR-BLOWN GASIFICATION WITH EXTERNAL SULFUR REMOVAL BEDS - CROSS FLOW

Two subsequent hot gas filtration tests were conducted during July 1989 using the original four cross flow filter elements. Tests No. 2 and 3, Tables 3.1 and 3.2. The integrated gasification system was operated in an air-blown mode, using external sorbent beds for sulfur removal. As in the commissioning test, precleaning cyclones were not used during this phase of testing.

Twenty-nine hours of filter operation were initially completed at a nominal temperature of 1250°F and with gas flow rates of 42-102 acfm at a pressure of 350 psig. Although the internal filter vessel heaters malfunctioned during this period of testing, a gradual temperature ramping of the filters occurred as a result of exposure to the hot syngas flow. The four cross flow filters experienced an inlet dust loading of 250 to 1,220 ppm, and achieved an outlet dust loading of 23 to 33 ppm. Testing was temporarily terminated as a result of a loss of slurry feed to the gasifier.

Six additional hours were logged by the cross flow filter system under similar air-blown gasification conditions after restart. During the six hour test period, the filter process heaters remained inactive, and the four cross flow filters experienced a nominal temperature of 1300°F, and gas flow rates of 24-91 acfm at 350 psig. Although high filter inlet dust loadings of 22,525 ppm were measured, satisfactory particulate collection efficiencies were demonstrated by the filter system as indicated by the 80-114 ppm outlet dust loadings. Excessive pulse cleaning frequencies were necessary to clean the four cross flow filters due to the abnormally high inlet dust loadings. Testing was ultimately terminated as a result of a leak in the gasifier air supply line.

After cooldown, the filter unit was disassembled and an inspection of the filter was performed. One of the four filter elements had developed a hairline crack on a dirty gas channel plate-to-plate interface. This filter element was replaced with another as-manufactured cross flow filter element. In addition to the filter hairline crack, three of the four cross flow filter gaskets had partially eroded and evidence of dust leakage was observed. These gaskets were replaced and testing resumed.

Testing resumed during July 1989 under air-blown gasification conditions with external sulfur removal. As in the previous test campaigns, precleaning cyclones were not utilised. Similarly, the filter process heaters remained inactive. The original four cross flow filter elements were exposed at a nominal temperature of 1300°F, and gas flow rates of 30-89 acfm for an additional 29 hours to inlet dust loadings of 270-2900 ppm. Outlet dust loadings ranged from 5-65 ppm. Testing was terminated due to a leak in the filter bypass valve, and temperature control problems in the gasifier slag knockout pot. After cooldown, a borescope inspection of the filter clean side showed no visible filter or gasket issues. The unit, therefore, was not disassembled.

3.3 HTHP FILTRATION UNDER AIR-BLOWN GASIFICATION WITH IRON OXIDE DESULFURIZATION - CROSS FLOW

During August 1989, the Texaco gasifier was operated under an air-blown gasification mode, with iron oxide added to the coal feed as a desulfurisation sorbent (Test No. 4). As in previous test campaigns, the precleaning cyclones were not utilised. The Westinghouse cross flow filter system operated for 63 hours at nominal temperatures of 1030-1430°F, and gas flow rates of 22-86 acfm at 350 psig. During this phase of testing, inlet dust loadings ranged from 280 to 2868 ppm, with outlet dust loadings of 59-115 ppm.

Once again the filter system heat-up was controlled by gradual ramping of the syngas flow. During the first 12 hours of filter operation, the pressure drop signal was lost as a result of a rupture in an internal pressure tap connection. The four cross flow filters were pulse cleaned on an equal time interval basis until a sparger tube was substituted for the failed pressure tap. Thereafter the filters were pulse cleaned on a very frequent basis (i.e., cycle time ranged between 15 seconds and 3 minutes). Pluggage of the cross flow filter dirty gas channels may have occurred when the sensor malfunctioned and proper cleaning periods could not be established.

After approximately 25 hours of filter operation, the pressure drop decreased abruptly from the baseline of 52 to 8 inches of water, following a pulse cleaning sequence. This suggested that at least one of the four cross flow filter elements had developed a serious breach. After an additional 38 hours, outlet dust loadings of 91 ppm were measured. Testing was ultimately terminated after completion of the Texaco sorbent test program.

Post-test inspection of the four cross flow filter elements indicated that three of the four filters were intact, showing no signs of delamination or cracking. These filters had acquired a total of 166 hours of hot testing during the first four test campaigns. The fourth filter element had been sheared off at the flange-to-filter body surface, and also appeared to have been unseated by the reverse pressure generated during pulse cleaning. This filter element initially had a thinner flange section in comparison to the other cross flow filter elements, and an abnormally sharp edge on the flange-to-body contoured surface. The filter body showed no evidence of cracks or delaminations.

Post-test inspection also indicated that three of the four dust seals were partially eroded. This suggested that the gasket material needed to be encapsulated and/or reinforced to minimise erosion and increase their durability during pulse cleaning. An aggressive testing campaign was conducted to identify alternate gasket seal materials. Materials were procured and subjected to prototypical seating stresses, thermal stresses, and transient hydrodynamic stresses that were expected to occur during delivery of a cleaning pulse. Based on maintaining seal integrity at high temperature, a Nextel fiber-MM® Mat composite gasket was designed and utilised in subsequent test efforts.

Post-test inspection of the filter vessel internal heaters indicated that the cold pin junctions had completely corroded, and were shorted due to moisture contamination of the electrical insulation. A cap was welded to the heater body, filled with a refractory potting compound, and coated with a high temperature moisture sealer. The heating elements were then mounted on the internal metal liner that was installed inside the filter vessel.

During this phase of the program, both Westinghouse and the Coors Ceramics Company considered various approaches for further extending the life of the cross flow filter element. This resulted from concerns that arose during simultaneous conduct of alternate Westinghouse-DOE/METC programs. From prior experience, delamination sporadically occurred along the mid-rib bond or gas channel seams during hot gas filtration testing. In order to minimize delamination, cross flow filter elements were manufactured using a single firing step to maximize the sintering reactivity of the mid-rib bonds or gas channel seams. In addition, the configuration of the dirty and clean gas channels was modified to enhance the cleaning effectiveness of the back pulse action. While the overall filtering area was maintained at 8 square feet, the number of dirty gas cross flow filter channels was increased from 158 to 198, and the number of clean gas channels was reduced from 4 to 3. This modification essentially reduced the size of the dirty gas channels such that a higher pulse gas flow velocity could be achieved through the clean-to-dirty gas channel wall, thus effectively increasing the dust cake removal efficiency.

3.4 HTHP FILTRATION UNDER AIR-BLOWN GASIFICATION CONDITIONS WITH EXTERNAL CALCIUM CARBONATE SPRAY DESULFURIZATION - CROSS FLOW

In November 1989, a 65 hour high temperature cross flow filter test was completed (Test No. 5). The Texaco system was configured to utilize a calcium-based sorbent slurry injection stream which was installed at the bottom of the upflow radiant cooler. In addition, cyclones were installed upstream of the filter vessel, with the hot by-pass line placed between the entrance to the cyclone and the outlet of the filter vessel.

During the initial 42 hours of HTHP filter testing, the gasifier was operated without sorbent injection. This period was marked by excessively short pulse cleaning cycles, ranging between 0.5 and 3 minutes. Because of the shortened intervals, the bypass valve was opened to provide operational flexibility for off-line cleaning. As a result of utilizing the upstream cyclone, the particle size of the filtered solids had apparently been reduced, thereby increasing the impedance of the filter dust cake and rate of pressure drop buildup.

During the final 20 hours of HTHP filter testing the gasifier was operated with a coarse dolomite slurry injection. In sharp contrast to the previous 42 hours of testing, the filter cleaning cycles ranged between 10 and 30 minutes. During both phases of testing, gas flow rates of 50 to 94 acfm at 350 psig were maintained through the filters. Inlet dust loadings to the cross flow filters ranged from 650 to 12,350 ppm, while outlet dust loadings ranged between 18.9 and 176 ppm. Testing was ultimately terminated when a plug formed in the Texaco sorbent injection system.

Post-test inspection of the filter system indicated that one out the four cross flow filter elements delaminated along a dirty gas channel seam, and that the body had been severed from the flange at a 45° shear angle. The failure mode of the cross flow filter was considered to have resulted from the frequent backpulsing required to dislodge the fine dust cake. The remaining three filter elements were found to be intact. However, during the disassembly process, one of these filters also delaminated.

The dust seal gaskets on the two remaining intact cross flow filters were found to be intact. The gasket on the delaminated filter, however, was eroded by the bypassing flow of the backpulse gas across the breached surface. One of the gaskets had been misaligned during filter assembly, and consequently was partially eroded.

Inspection of the internal surface of the filter vessel liner clearly showed indications of a gas rebound path across the inlet baffle plate. This observation suggested that the gas was deflected by the baffle plate, which then formed eddies on the back surface of the filter vessel close to the bottom element on the second plenum. Throughout this test program, three cross flow filter elements which had been mounted at the bottom position of plenum No. 2 experienced failure during high temperature, high pressure testing.

In an attempt to eliminate direct impingement of high velocity gases and solids on any filter element, efforts were directed to designing a retrofit of the filter unit internals. Prior to subsequent testing at Texaco, the filter unit system redesign was evaluated at Westinghouse in our cold flow model test facility. This work is summarised in Section 4.

3.5 HTHP FILTRATION UNDER OXYGEN-BLOWN GASIFICATION CONDITIONS WITH EXTERNAL SULFUR REMOVAL - CROSS FLOW - TEST NO. 6

Based on the information generated from the cold model and vibration tests, the design of the filter unit was modified, (Figure 3.2). The modified design included a coaxial shroud around the filter plenum to promote uniform gas distribution and downflow. In addition the filter plenums were redesigned to hold four filters each instead of two, and the filter mount was redesigned to include a rugged swivel bar clamp to more evenly distribute the load along the filter flange. Composite gaskets consisting of Nextel fabric and 3M's MM Mat were substituted for the previous Interam gasket seals.

Operation of the Texaco gasifier resumed in August 1990, after replacement of the dolomite sorbent with a calcined limestone sorbent. During initial system pressurization following gasifier light-off, a hot spot was observed in the quench pot, and a system shutdown was necessary.

Following system repair and other facility maintenance delays, the high temperature, high pressure filter testing was resumed in January 1991 (Test No. 6). During this phase of testing, the gasifier was operated in an oxygen-blown mode without in-situ sulfur sorbents. The hot gas filtration unit consisted of two plenums, each containing

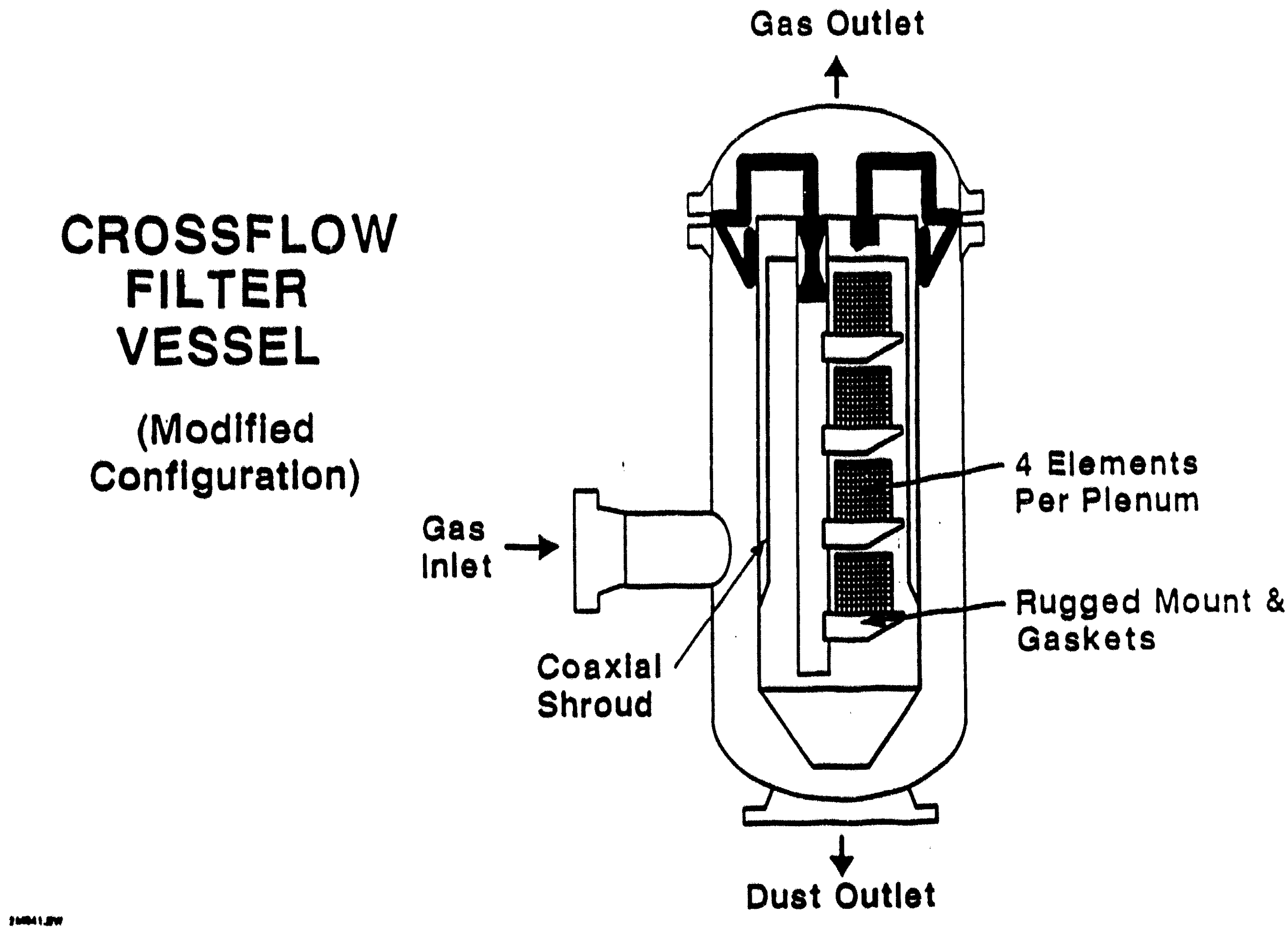

Figure 3.2 - Schematic of Modified Cross Flow Filter Unit

four cross flow filter elements. A precleaning cyclone which was previously installed to separate spent limestone particles injected downstream of the gasifier continued to operate during this test. A cascade impactor particle sampling train, designed and built by SRI, was also implemented for the inlet filter leg.

In Test No. 6 the filter system was preheated by ramping the gasifier slipstream flow through the radiant cooler. In this manner a nominal filter temperature of 1200°F was achieved in five hours. The filter system was operated at a nominal flow rate of 60 acfm with an effective face velocity of 1 fpm. Inlet dust loadings ranged between 1,170 and 1,934 ppm, with a mass mean particle size diameter of ~4 μm (established from the cascade sampling train). Approximately 20 percent of the inlet dust loading was comprised of particles that were less than 1 μm.

During filter operation, hot gas cleaning was performed with a blowback tank pressure of 900 psig which typically reduced the pressure drop across the filter from 95 to 50 inch wg. Pulse cleaning frequencies varied between 4 and 6 minutes during steady state operation. After 33 hours of operation, outlet dust loadings ranged between 183 and 788 ppm, and the filter system was taken off-line. A total of 42 hours of operation was achieved. Filter unit pressure drop characteristics for this test run are provided in Appendix C.

Post-test inspection of the filter system indicated that the two bottom filters on each plenum were wet and had delaminated. The bottom filter on one plenum also appeared to have sustained a V-shaped fracture across the top closed section of the filter. One filter, located at the second position from the bottom, also appeared to have experienced delamination along a dirty gas channel seam. Dust, however, was contained along the dirty gas channel surfaces in the vicinity of the delamination. Although the remaining five cross flow filters were intact, their channels were filled with dust which had apparently been reentrained and deposited during pulse cleaning.

After removing the three damaged cross flow filters, a pool of water was seen inside the metal fixtures that supported the cross flow filter elements. Approximately 150 pounds of solids and 100 gallons of water were drained from the bottom of the ash hopper. The source of the water leak was not conclusively established. All four bottom cross flow filter (three damaged and one intact filter element) were replaced with new filter elements prior to subsequent testing.

Of the four bottom filters that were removed, the one which remained intact was subjected to permeability characterization. Testing indicated that the filter retained only 5 percent of its original permeability after exposure to the Texaco gasifier dust. This is viewed as a substantial loss in permeability in comparison with the 20 to 30 percent retention by filters which operated under pressurized fluidized-bed combustion conditions. The low residual permeability, however, does not account for the relatively high baseline Δp experienced during testing. The projected baseline Δp, based on the actual face velocity, should have remained below 6 inch wg, in comparison to the >30 inch wg that was actually experienced. This suggests that the plugged filters resulted from either poor cleaning, or from earlier testing where the filters were permitted to operate for long periods without cleaning.

In view of the anomaly in the baseline pressure drop described above, and the possibility of ineffective cleaning, an evaluation of the pulse cleaning system was made. This analysis showed that the pulse jet issuing from the pulse nozzle may not have been attaching to the throat of the eductor, limiting the effectiveness of the filter cleaning. A modified venturi design with a long throat section, was implemented.

3.6 HTHP FILTRATION UNDER OXYGEN-BLOWN GASIFICATION CONDITIONS WITH EXTERNAL SULFUR REMOVAL - CROSS FLOW - TEST NO. 7

During May 1991, the Texaco gasification system was operated in an oxygen-blown gasification mode (Test Campaign No. 7) using external sulfur sorbents. Precleaning cyclones were not used during this phase of testing. A significant filter temperature transient was experienced during initial pressurization (i.e., after gasifier lightoff) which exceeded the recommended cross flow filter system ramp rates. Significant fluctuations in the Texaco gasifier operation (flow and temperature) were experienced making it difficult to maintain steady state conditions during the 60 hour filter test period. During testing the inlet sample lines were frequently plugged, possibly indicative of high particulate loadings. During the last 24 hours of testing, the filter Δp measurement failed. Texaco experienced an overheating and rupture of one of its pressure vessels which necessitated rapid shutdown of the system. This event may have imposed a high Δp across the tubesheet and filter unit, contributing to the damage incurred within the filter vessel. The tubesheet plate had completely separated from the expansion cone, and all eight cross flow filters were damaged. Inspection of the ash in the collection hopper revealed the presence of broken pieces from at least one cross flow filter.

Since the repair and replacement schedule for the damaged tubesheet and filters would delay the planned Texaco testing program, alternative filter choices were explored. An existing candle filter tubesheet and plenum assembly was available that could be easily adapted to the Texaco pressure vessel. Benefits of testing a candle filter array at Texaco included:

1. Direct comparisons between candle and cross flow filter systems, to determine if the previously observed characteristics are indicative of the process gas, type of ash, or geometry of the filter.

2. Supporting the design and operation of larger scale DOE funded candle filter installations by demonstrating the feasibility of pulse cleaning a large candle array (19 candles) from a single nozzle source.

3. Demonstrating the durability and adequacy of the candle mount and seals used in the larger scale program.

3.7 OXYGEN-BLOWN GASIFICATION TESTING OF A CANDLE FILTER CLUSTER WITH EXTERNAL DESULFURIZATION AND REGENERATION - CANDLE

In this test, Test No. 8, a 19-candle filter array was implemented, replacing the cross flow filter test section. Seventeen 1.5 m silicon-carbide Schumacher F40 Dia Schumalith candles, and two 1 m alumina/mullite Coors Ceramics candles were housed in individual filter mounts and connected to a common plenum section, Figure 3.3.

During Test No. 8, Texaco operated the gasifier in an oxygen-blown mode with an external sulfur bed that incorporated off-line regeneration. At operating conditions, a maximum temperature of 1400°F was experienced by the candle filter array. Table 3.4 provides a summary of the filter operating data. During the sulfidation phases of the external sorbent bed (Phase I, II, III, and V in Table 3.4), the candle filters experienced gas flows of 70 to 90 acfm. During sorbent regeneration (Phase IV), the flow of gas through the filters was reduced to approximately 60 acfm.

During the initial twelve hours of operation with coal (Phase I), the candle filter operating baseline pressure drop ranged from 4 to 10 inch wg. Following this initial period, the gasifier flow was increased from approximately 70 to 90 acfm. The baseline filter pressure drop increased significantly, ranging from 50 to 70 inch wg, but remained reasonably stable once steady state flow conditions were established (Phase II, III, and V). At low flow conditions (i.e., 60 to 70 acfm, Phase IV), baseline pressure drop remained constant at ~30 to 40 inch wg.

The resulting pressure drop through the candle filter system indicated that the overall operating characteristics did not appear to differ significantly from those of the cross flow filter system. This suggested that the relatively high operating Δp experienced in the gasification system was probably process dependent and not associated with the type of filter element.

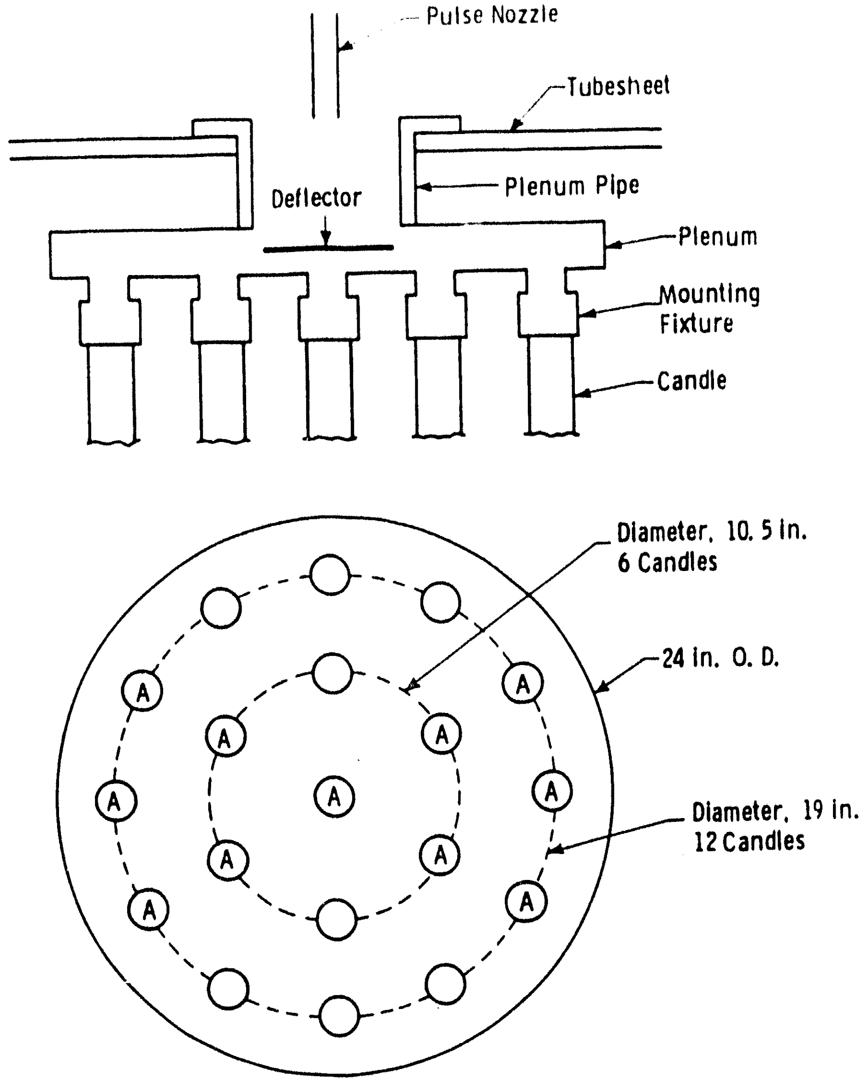

Figure 3.3 - HTHP Candle Array Arrangement

Table 3.4 - Nominal Filter Performance Data Test No. 8, August 1991

Test Period	Elapsed Time Hrs	Flow SCFH	Filter Temp °F	Face Velocity Ft/Min	Nominal Cycle Times Min	Operating Pressure Drop, in wg Baseline Range	Operating Pressure Drop, in wg Trigger Range
Gasifier Startup	2	0 to 19,000	280 - 770	0.6		-	-
Phase I	9	23,000 29,000	770 to 1385	0.7 to 1.3	60 - 30	4 - 10	40 - 50
Phase II	2.5	36,800 38,000	1400	1.6 1.7	2 - 10	10 - 70	50 - 100
Phase III	5.0	34,500	1400	1.5	4 - 10	50 - 70	100 - 115
Phase IV	8.0	28,000	1240	1.2	5 - 7	30 - 40	60 - 90
Phase V	5.0	32,000	1325	1.4	1 - 4	50 - 90	90 - 115
Phase VI	4.5	27,000 20,000	1300 1000	1.2 0.7	7 and up	40	100 - 75
Phase VII	1.0	2000 6400	1000 450	0.7 0.2	>60	40 - 5	75 - 20
Shutdown							

Two outlet and inlet samples were taken during candle filter operation. Inlet dust loadings ranging from 1,000 to 2,000 ppm were identified, typical of previous cross flow filter tests. Outlet loadings appeared to be dust free, but contaminated with debris. After ~25 hours operation, testing was terminated when a high filter system pressure drop resulted (i.e., ΔP exceeded gauge readouts), and the filter bypass leg suffered an apparent blockage. Subsequent inspection of the gasifier unit indicated that the gasifier slag removal system had malfunctioned, causing excessive ash carryover.

A borescope inspection of the filter unit was conducted and indicated that the filters had not experienced any obvious problems. A flow test using ~10,000 acfm nitrogen gas was also conducted to determine if the filters suffered significant blinding. The flow test results indicated nominally expected pressure drop characteristics.

3.8 OXYGEN-BLOWN GASIFICATION TESTING OF A CANDLE FILTER CLUSTER WITH EXTERNAL DESULFURIZATION AND REGENERATION - TEST NO. 9 - CANDLE

A second test run was conducted utilizing the 19-candle array previously operated during Test No. 8. Test No. 9 was a repeat of the earlier test plan, i.e., external desulfurization and regeneration. Approximately 34 hours of operation was achieved (including time to change process conditions).

The gasifier was operated in the oxygen blown mode with an external sulfur bed that was regenerated off-line. Table 3.5 summarizes the test results. Filter test operations are divided into five (5) test segments:

Gasifier Startup
Phase I - Bed Heatup
Phase II - System Restart
Phase III - Sulfidation
Phase IV - Regeneration

Table 3.5 - Summary of Texaco Gasifier, Hot Gas Filter (19-Candle Array) Test - Test No. 9

Test Segment	System Pressure psig	Filter Temperature °F	Flow acfm	Filter Pressure Drop, in wg Baseline Range	Filter Pressure Drop, in wg Trigger Range	No. of Cleaning Cycles	Time at Conditions Hrs
Startup	0-385	400-875	0-38	-	40	1	4.0
Phase I	363	875-1100	38-60	9-12	40-50	3	2.0
Phase II	387-347	900-1330	50-80	11-29	50-60	12	4.0
Phase III	350-360	1300-1425	90	44-200	>250	~275	10.0
Phase IV	350-360	860-1000	40-30	40-80	60-160	~180	7.0

NOTE: Time at conditions excludes time between test phases.

The Westinghouse filter was first preheated to about 400°F utilizing the same aspirated hot gas flow that preheats the gasifier system prior to gasifier lightoff. At lightoff, the system is pressurized to about 350 psig and flow slowly increased to operating value.

During Phase I, the Texaco external sulfur beds are brought to the desired operating temperature using an external heating source, while operating the filter to remove particulate from the generated fuel gas. Relatively low filter pressure drops were experienced during this period. Just prior to the initiation of the desulfurization test, overheating of the upstream transfer line (unrelated to the filter) occurred, forcing a temporary shutdown for repair.

With correction of the overheated transfer line problem, operation was resumed with continued preheating of the sulfur bed and filtering of the fuel gas, Phase II. During this phase, flow was increased to about 80 acfm. Stable and acceptable operation of the filter was experienced through both Phase I and Phase II.

Following the preheat of the sulfur beds, part of the filtered fuel gas flow was diverted through the sulfur beds to begin the sulfidation portion of the test program, Phase III. Pressure drop increased dramatically with the inability to sustain a stable baseline condition within the pressure transmitter range. Various actions were taken to determine if the observed response was real or instrument related. Cleaning of the filter was set on a timer mode (about 3 minutes) and the system allowed to operate while Texaco completed their sulfidation run. The increased pressure drop experienced during Phase III results from an increase in the syngas flow when the sorbent beds are being operated.

Following sulfidation, the fuel gas flow through the filter was reduced in an effort to reduce system pressure drop. Over the regeneration period, Phase IV, quasi-steady operation was indicated with pressure drop responding to flow changes. At this point, it became evident that a plug had occurred in the bypass leg, thus preventing the ability to divert flow. Upon restart of the sulfidation cycle, pressure drop again increased and would have exceeded pressure transmitter limits if operation continued. A decision was made to shut down and identify the pluggage problem.

Subsequent inspection of the gasifier unit showed a problem had occurred in the gasifier slag removal system causing excessive ash carryover. Following testing, a borescope inspection of the filter unit was conducted that indicated the filter had not experienced any obvious problems. A flow test was also conducted to determine if the filters suffered significant blinding. About 10,000 acfm of nitrogen gas was passed through the filter and pressure drop measured. These tests indicated nominally expected pressure drop characteristics. On this basis, a decision was made not to open the system for any additional inspection or cleaning, but prepare for a late November or early December test.

3.9 OXYGEN-BLOWN GASIFICATION TESTING OF A CANDLE FILTER CLUSTER WITH EXTERNAL DESULFURIZATION AND REGENERATION - TEST NO. 10 - CANDLE

A third test run, Test No. 10, was conducted utilizing the 19-candle array previously operated during Test No. 9. The gasifier was operated in the oxygen blown mode with an external sulfur bed that was regenerated off-line. Table 3.6 provides a summary of the filter operating parameters during this test program. Filter unit pressure drop data for this test run are provided in Appendix C.

The gasifier and filter units were preheated by aspirating hot gas through the gasifier unit. With regard to the filter, the purpose is to preheat the unit above fuel gas dew point conditions. After approximately 36 hours of preheat operation, (with some minor stops and restarts) a filter temperature of about 330°F was achieved prior to

Table 3.6 - Nominal Filter Performance Data, Test No. 10, December 1991

Test Segment	Filter Temperature °F	Flow acfm	Filter Pressure Drop, in wg Baseline Range	Trigger Range	No. of Cleaning Cycles	Time at Conditions Hrs
Preheat	0 - 330	--	--	--		36
Startup	330 - 1000	20 - 87	30 - 130	50 - 200	140	7
Phase I	1400	80 - 90	150 - 200	200 - 250	110	5
Phase II	1130	45	75	100	44	5
Phase III	1400	80 - 90	200	250	130	5.5
Phase IV	1150	50	130 - 150	170 - 200	130	8
Phase V	1400	80 - 90	200	250	50	3
Phase VI	1150	40	100	150	60	5

gasifier lightoff. During this period, the filter unit operated at about ambient pressure, and was pulse cleaned on a 5 to 10 minute cycle to prevent buildup of ash or other debris that may have collected in the lines from previous tests. The cleaning was done using a nominal 220 psi N_2 source.

During startup the gasifier is ignited, pressurized and flow initiated through the filter system. Filter temperature is slowly increased from the initial preheat value to about 1000°F. This required about 7 hours of operation.

Filter pressure drop increases due to both increasing temperature and flow conditions. Over this period, flow was increased from about 20 acfm to about 47 acfm. Following the initial couple of cleaning cycles, the filter was set on an automatic cleaning cycle initially corresponding to 5 minutes, but reduced to 3.5 minutes to keep the trigger pressure drop below about 150 in wg. Following initial preheat, the filter was taken off-line by opening the bypass valve in an effort to increase the rate of preheat to the external sorbent beds. During this approximately 4 hour period, the filter continued to operate, but at low pressure drop because of the significantly reduced flow. Following this action, the filter was brought back on-line and the flow increased to continue the sorbent bed heatup operation. Again, filter pressure drop increased due to increased flow and temperature. Flow ranged from about 50 acfm to 87 acfm (1.7 ft/min) while the average temperature across the filter increased from about 750 to 1390°F.

Following satisfactory preheat of the external sulfur beds, Texaco initiated their sulfidation cycle, Phase I, which lasted approximately 5 hours. During this period, flow adjustments were made through the filter in an effort to keep the trigger pressure drop below 250 in wg which represents the upper limit of the measuring gauges (transmitter). Again, cleaning of the filter was on an automatic timing cycle corresponding to 2-1/2 to 3 minutes. Flow through the filter is estimated at about 80 to 90 acfm (1.7 ft/min). Average filter temperature remained about constant (1400°F).

Following sulfidation, the sorbent bed was taken off-line for regeneration, Phase II. During this 5 hour period, flow to the filter system was reduced and pulse cleaning intervals were increased to between 5 to 10 minute cycles. The filter baseline pressure drop decreased from 180 in wg to about 170 in wg. Flow at this condition was approximately 45 acfm while filter operating temperature decreased to 1130°F.

Following regeneration, syngas flow was again diverted through the sorbent bed, Phase III. During this 5-1/2 hour period, flow through the filter was initially increased, with a corresponding increase in baseline pressure drop followed by quasi-steady operation. Again, pulse cleaning varied from 5 to 2 minutes.

Following completion of the second sulfidation cycle, the sorbent bed was again taken off-line for regeneration, Phase IV. During this nominal 8 hour period, filter flow was reduced, but maintained at approximately 50 acfm. Filter pressure drop remained reasonably stable with the filter being cleaned on 3 to 5 minute cycles.

Following the second regeneration cycle, syngas was again diverted through the sorbent bed to begin a third sulfidation cycle, Phase V. During this nominal 3 hour period, the flow rate through the filter was increased (nominally 80 to 90 acfm) and maintained to keep the maximum filter pressure drop below 250 in wg.

Following the sulfidation cycle, a third regeneration cycle was initiated, Phase VI. During this nominal 5 hour period, flow through the filter was decreased (nominally 40 acfm) and cleaning cycle time increased. Following this regeneration cycle, operation of the gasifier was terminated completing the test program.

3.10 OXYGEN-BLOWN GASIFICATION TESTING OF A CANDLE FILTER CLUSTER WITH EXTERNAL DESULFURIZATION AND REGENERATION - TEST NO. 11 - CANDLE

A fourth test run, Test No. 11, was conducted utilizing the 19-candle array previously operated during Test No. 10. The gasifier was operated in the oxygen blown mode with an external sulfur bed that was regenerated off-line. Table 3.7 provides a summary of the filter operating parameters during this test program.

Normal preheating of the filter was accomplished by aspirating hot air from the gasifier unit that was being preheated using a propane torch. Some difficulties were encountered with this approach and an alternate N_2 preheat was utilized.

At gasifier lightoff, the system is pressurized to about 350 psig and syngas flow and temperature are slowly increased to operating value. Filter system pressure drop first increased to expected value (based on previous test). Following initial startup, the filter inlet temperature increased above 1000°F and the pressure drop increased significantly. Although pressure drop was high, filter operation appeared stable.

Following the preheat of the sulfur sorbent beds, part of the filtered syngas was diverted through the sorbent beds to begin the sulfidation portion of the test program, Phase I. Shortly into this testing, the syngas flow was reduced to control sorbent bed temperature with the filter pressure responding accordingly. Flow control of the system could not be maintained due to non-filter related problems, and the gasifier operation was shut down.

Table 3.7 - Nominal Filter Performance Data, Test No. 11, July/August 1992

Test Segment	Dates	System Pressure psig	Filter Inlet Temperature °F	Flow acfm	ΔP Baseline in wg	ΔP Trigger in wg	No. of Cleaning Cycle	Time at Conditions Hrs
Preheat	7/8/92 7/13/92	0	70 - 270	-	10 - 30		>250	~96
Gasifier Startup	7/13/92	0 - 365	270 - 982 982 - 1640	0 - 52 54 - 57	16 - 34 150 - 170	50.57 198 - 240	4 ~170	4 8.5
Phase I (Desulfurization)	7/13/92	351	1680 1430 - 830	63.4 63 - 13	198 198 - 30	240 240 - 46	20 ~110	1 5.5
		Shutdown - Non Filter Related Operating Problem						
Preheat Restart (Reverse N_2 Flow)	7/21/92	0	70 - 335	-	-			24
Gasifier Restartup and Bed Preheat	7/22/92 7/24/92	0 - 350 350 350	335 - 500 1090 1680	40 88	14 - 26 160	35 - 39 181	14 60	2 8.5
Phase IA	7/24/92	350	1800-1260	88 - 56	180 - 240	off scale	25	3
Phase IB	8/11/92	350	1693	93	63	130	9	1.5
Phase IIB	8/12/92	350	1400	97	52	110	35	4.6
Phase IIIB	8/12/92	350	1700-1300	97 - 38	126 - 114	130	19	2.5
Phase IVB	8/12/92	350	1440	87	168	141	36	6
Phase VB Shutdown	8/12/92	350	1508	73	234	218	15	2.4

Following the initial shutdown and system maintenance, the gasifier test program was restarted. Several stops and starts were incurred during this period. A filter operating temperature of over 1600°F at the inlet (1300°F outlet) was measured. Filter pressure drop again appeared to increase with both flow and syngas temperature consistent with the initial startup but not in the expected proportion to temperature and flow effects.

Following preheat of the sulfur sorbent beds, part of the filtered syngas was diverted through the sorbent beds to begin the sulfidation portion of the test program, Phase 1A. A filter inlet gas temperature over 1800°F was measured. Since the baseline filter pressure drop was near the upper limit of Δp transmitter range, an 8 minute cleaning cycle was implemented. Stable operation of the filter appeared to be achieved over the 3 hour test period. Testing was terminated when a hot spot occurred on the transfer pipe between the gasifier and radiant cooler.

Following repair of the transfer pipe, testing was reinitiated, Phase 1B. Following preheat, gasifier lightoff and sorbent bed preheating, part of the filtered syngas was diverted through the sorbent beds to begin the sulfidation portion of the test program. Filter pressure drop was lower than anticipated based on the earlier testing.

Following sulfidation, the sorbent beds are regenerated off-line while the filter continues operation on the syngas flow, Phase IIB.

Following regeneration, syngas flow was diverted back through the sorbent beds, Phase IIIB. During this period syngas flow was reduced to compensate for a higher flow resistance encountered in the sorbent beds. This suggests the possibility of significant dust penetration through the filter system consistent with the somewhat lower filter pressure drop.

Again, following sulfidation, the sorbent beds are regenerated off-line, while the filter continues operation on the full syngas flow, Phase IVB.

Following regeneration, syngas flow was diverted back through the sorbent beds, Phase VB. It appeared that during this test phase, filter pressure drop returned to the earlier higher levels. Following this phase, the test program was completed and the gasifier was shut down.

No filter particle sample was accomplished during operations due to an inoperable sampling system. Inspection of the filter revealed three broken candles. Based on the sorbent bed pressure drop, this event likely occurred during Phase IIIB as noted above.