PERFORMANCE EVALUATION OF A CERAMIC CROSS-FLOW FILTER
ON A BENCH-SCALE COAL GASIFIER

Westinghouse Principal Investigators
D. F. Ciliberti and T. E. Lippert

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DOE Project Officer: Randall J. Dellefield
Department of Energy
Morgantown Energy Technology Center
P.O. Box 880
Collins Ferry Road
Morgantown, WV 26505

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OVERALL PROGRAM OBJECTIVES

The Department of Energy is currently supporting a program that will aid in the development of cross flow filtration technology as applied to combined cycle power generation with coal gasification. The stated overall goal is to gain information on both the operational and economic feasibility of the implementation of cross flow filtration for various gasifier options. Westinghouse has prepared a comprehensive program that will lead directly to these program goals in an efficient manner.

The proposed program is composed of three major technical tasks. Task 1 is directed at the design and actual test of a cross flow filter at a DOE bench scale gasifier. Task 2 is composed of several smaller theoretical and experimental efforts that are intended to firm up areas where engineering and design principles are lacking or considered inadequate. The third task is intended to integrate the results of the first two tasks in a conceptual design and cost analysis such that proper economic perspective for the filter concept can be gained. A brief summary of the approach taken in the technical tasks is presented in the following discussion.

In the conduct of Task 1, we will design, fabricate, install, and operate a cross flow test system at the AGC. The actual test article will incorporate provisions for a scaled down cross flow element that will accommodate all of the gasifier flow. From this element, we will gain information on filtration parameters such as efficiency, pressure drop, and cleanability. The element will be instrumented with high speed differential pressure transducers that will allow us to quantify the pulse jet parameters that are required for successful blow back cleaning. These will subsequently serve as inputs to scaling models for full size module calculations.

In Task 2 we propose to conduct a series of independent tests. The efforts center on the following areas: 1) a task to develop a filter element with improved mounting and delamination properties, 2) a task to refine our model that describes the dynamics of pulse jet cleaning, 3) a task to quantify the dust cake properties of char and sulfur sorbent fines, and 4) a chemical stability test of the cross flow filter in a simulated gasifier environment.

The third technical task will involve the integration of new test data and model refinements into a sound conceptual design for at least three gasifier systems. Westinghouse personnel that have had past and current responsibility for commercial gasification systems design and cost analysis will assume the primary responsibility for this task. We are confident that the approach of coupling a sound scientific data base and scaling methodology with a broad systems understanding and capability will result in a sound conceptual design and costing basis.

PROJECT STATUS REPORT FOR JULY THROUGH SEPTEMBER 1985

TASK 1 - Vessel Design, Supply Installation and Testing

Installation:

The filter housing pressure vessel and internals was totally fabricated and checked out by the end of June. It was shipped to DOE METC on July 8th and received there on the 10th. Westinghouse project engineers and technicians visited the METC test site on the 15th of July, in order to check out the vessel and control cabinet and to prepare for installation work. Both vessel and instrument cabinet survived the shipping well and plans were made for project technicians to begin installation later that week. During the 18th and 19th the following tasks were completed by Westinghouse technicians:

- 1) The differential pressure transmitter for the filter was calibrated, mounted and wired to the control panel. The accompanying local differential pressure gauge was also installed and plumbed in.
- 2) The remainder of the pressure vessel was painted with temperature sensitive paint.
- 3) A minor modification to the control panel wiring was made because DOE had changed their original plan that called for DOE control of the by pass valve. Currently Westinghouse will have control of the by pass valve and will not have to request DOE operators to enable our relay to the valve control.

- 4) Thermocouple hook ups were completed including the following: a control sensor for the heater system, an auxiliary back up sensor for the controller, a filter inlet temperature and a filter outlet temperature.
- 5) The blow back system was installed with both electrical and plumbing connections completed.
- 6) The pulse pressure sensors were installed.
- 7) The power connections to the vessel heater system were made as were the control circuits.

By the end of the week almost all of the filter system installation had been completed with only the actual installation of the cross flow filter and some minor electrical work remaining. Figure 1 shows the position of the control panel and filter housing in the system. Figure 2 is a full view of the filter pressure vessel, and Figure 3 presents a view of the vessel, the dust injector, the in line gas heater and the by pass line. By the end of July it appeared that the actual start date for the HTHP filter tests would be August 5th and that the testing would likely run straight through to August 16th.

On August 1 and 2 Westinghouse technicians worked at the METC test site to actually mount the cross flow filter and install it in the pressure vessel. Subsequent to the installation of the filter, the vessel was closed and pressure tested. Some leaking was discovered at the electrical lead throughs for the heaters. These minor leaks were fixed and the filter system was considered to be ready for test.

Figure 1 - Westinghouse Cross Flow Filter Control Panel And Vessel

Figure 2 - Westinghouse Cross Flow Filter Vessel Installed At MHL

Figure 3 - View of METC Hot Gas Cleaning With Cross Flow System

Cross Flow Filter Testing at METC

8/5:

On August 5th attempts were made to initiate the actual test program. At 9:00 a.m. the system flow was brought to a flow of 1000 scfh of N₂ at a system pressure of 250 psig and the system was gradually heated with the use of the electric process gas heater and the filter vessel heaters. The initial pressure drop of the filter (WCXF1) was about 1.0 in. wg. By about 5:00 p.m. the system had been heated to 720°F, however, some difficulty was being experienced with the process gas heater, so the test was shut down to inspect the heater.

In the next few days it was determined that an internal bolted and flanged connection of the heater had loosened, and caused leaking from the shell side of the heater to the heated process gas side. The solution was to seal weld this joint.

8/9:

The system was back in operating condition by August 9, and at 8:15 a.m. the system was brought to a flow 1250 scfh N₂ at a pressure of 250 psig and a temperature of 560°F. The initial filter pressure drop was about 3-4 in. wg. By 9:30 a.m. the system had been brought to a temperature of 830°F and the switch from N₂ to process gas was made. As can be seen in Figure 4, from 9:30 to 11:30 a.m. the pressure drop rose fairly constantly to a value of 10 in. wg. and the system temperature rose to 950°F. During this period DOE sample (8-9 0939-1053) indicated an inlet concentration of approximately 10.98 mg/scf or 410 ppm. At this time we began to lose temperature and it was discovered that the process heater had blown three fuses.

Figure 4 - Cross Flow Filter WCXF2 (8/9/85)

Cross flow filter WCXF-2 (8/14/85) $T = 1400^{\circ}\text{F}$, $P = 250 \text{ psig}$, $V_f = 4.89 \text{ ft/min.}$

Figure 4 (continued)

Cross flow filter WCXF-2 (8/14-15/85) T = 1400°F, P = 250 psig, V_f = 4.89 ft/min

Figure 4 (continued)

A decision was made to finish out that day shift with the temperature that the line heaters could provide. By about 2:30 p.m. the temperature had steadied at about 520°F. At this time the pressure drop had climbed to 17.9 in. wg. and the first pulse jet cleaning sequence was initiated. It consisted of a single 0.1 second pulse from a reservoir charged to 300 psig. During this initial pulse the system was placed in the bypass mode of operation. The internal pressure rise generated by the pulse was monitored (Figure 5) and it was found to be about 0.75 psi. Even with this very gentle pulse, the filter's pressure drop was decreased from 17.9 to 2.7 in. wg.

As can be seen in Figure 4, the remainder of the day consisted of a nearly 2 hr cycle to 10 in. wg. and a short cycle to 6.6 in. wg., each being punctuated by a successful pulse of 300 psig for 0.1 sec.

During the afternoon DOE samples were taken that indicated an inlet loading of 200 ppm and an outlet loading of between .09 to 4.28 mg/scf. The estimated filter efficiency was determined to be 99.18% which seemed a bit low, however, there was considerable variability in the outlet probe, and total outlet measurements, so there may be some question about the precision of the calculated efficiency.

In the period from 8/9 to 8/13 repairs were made on the process heater and a new test was initiated on August 13.

8/13-8/15:

At 8:00 a.m. 8/13 the filter system was at 655°F, 200 psig and had a pressure drop of 7.1 in. wg. at a flow of 960 scfh of N₂. By about 9:30 a.m. the system was switched to process gas at a flow of 1060 scfh and a temperature of 930°F and an initial pressure drop of 7.6 in. wg. The filter

Figure 5 - Pulse Trace of the Cleaning Pressure Differential Generated Inside Filter Plenum Relative to Dirty Side of Filter During a 0.1 sec Pulse from a 300 psig Reservoir to a 250 psig System

and system ran in a fairly steady fashion for the next 8-1/2 hours with nine cycles from 5 or 6 to 18 in. wg. and cycle times from 30 to 70 minutes. The flow was maintained at 1050 scfh, and at 1100°F and 250 psig; this gave rise to a filter face velocity of 2.6 ft/min. DOE inlet samples during this time indicated a typical inlet concentration of about 400 ppm during the first few hours. Later in this period the dust feeder was turned on and DOE sample (8-13 1320-1620) indicated an inlet loading of 100.5 mg/scf or 3700 ppm.

At about 6:00 p.m. (hr = 16.5 Fig. 4), the system flow was increased at a slow rate so that by 6:30 the system flow was at 1430 scfh. With a system temperature of 1100 to 1175°F the filter face velocity was approximately 3.5 ft/min. During the next 8-1/2 hr period (hr = 16.5 to hr 25) the system ran smoothly with measured efficiencies of 99.9+%, inlet concentrations from 3700 to 4100 ppm and cycle times of about 25 min for the pressure drop to rise from its base value of 12-15 in. wg. to the trigger pressure drop of 30 in. wg.

At 2:20 a.m. on 8/14 the system flow was again increased; this time from 1400 to 1750 scfh. In the subsequent several hours the temperature rose to about 1200°F giving a filter face velocity of 4.3 ft/min. This mode of operation was maintained constant over the next 25 hours of operation with the exception that the system temperature gradually worked its way up to a value of 1400°F giving face velocity of 4.9 ft/min. Cycle times during this period were typically 20-25 minutes to go from 14 to 30 in. wg. During this time DOE samples indicated a generally increasing inlet loading to the filter ranging from about 4500 ppm at the start of this period to values of about 18,000 ppm (hr 42-44) and then back to 2500 ppm near hour 48.

Table 1 -PHYSICAL DATA FOR PARTICULATE SAMPLES TAKEN DURING HGC TEST 8/9 TO 8/15/85

SAMPLE	SAMPLING TIME (MIN)	PROBE POSITION	SAMPLE FLOW RATE (SCFM)	FLOW SAMPLED (SCF)	WEIGHT PARTICULATES (GRAMS)	MASS LOADING (MG/SCF)	MEAN	
							VOLUME (MICRONS)	POPULATION DIAMETER (MICRONS)
8-9 0939-1053	61	INLET	0.240	18.960	0.2081	10.98	-	-
8-9 1250-1550	180	INLET	0.260	54.960	0.2986	5.43	1.92	0.87
8-9 1300-1640	220	OUTLET	1.04	260.960	1.1175	4.28	2.02	0.90
8-9 1401-1411	10	TOTAL OUTLET	17.50	223.432	0.0195	0.09	-	-
8-13 0941-1111	90	INLET	0.273	27.210	0.2990	10.99	-	-
8-13 1320-1620	180	INLET	0.273	57.780	5.8090	100.54	22.97	14.54
8-13 1024-1620	356	OUTLET	0.273	407.240	0.2498	0.61	5.62	2.15
8-13 1320-1620	180	TOTAL OUTLET	17.50	4022.160	0.2573	0.06	7.59	5.38
8-13 2005-2305	180	INLET	0.273	56.340	6.3204	112.18	17.45	10.59
8-13 2005-2305	180	OUTLET	1.09	222.696	0.0270	0.12	7.62	4.95
8-13 2000-2300	180	TOTAL OUTLET	23.33	4852.212	2.2505	0.46	15.87	10.32
8-14 0340-0633	173	INLET	0.456	90.888	11.0732	121.83	10.06	3.59
8-14 0340-0633	173	OUTLET	1.82	340.060	0.1593	0.47	8.51	5.62
8-14 0330-0631	181	TOTAL OUTLET	29.17	5629.635	0.7305	0.13	4.98	3.68
8-14 1100-1400	180	INLET	0.456	97.920	13.7332	140.25	32.51	17.43
8-14 1116-1416	180	TOTAL OUTLET	29.17	6031.692	6.6728	1.11	6.17	3.36
8-14 1623-1723	60	INLET	0.456	30.720	8.2418	268.29	20.61	14.65
8-14 1917-2017	60	INLET	0.456	32.160	15.5777	484.38	27.35	16.84
8-14 1733-2034	181	TOTAL OUTLET	29.17	6722.963	27.8902	4.15	23.73	16.02
8-14 2200-2300	60	INLET	0.456	30.240	6.3809	211.01	23.98	15.48
8-14 2153-2353	120	TOTAL OUTLET	29.17	4281.168	13.2095	3.09	6.38	3.65
8-15 0038-0138	60	INLET	0.456	31.440	2.0778	66.09	23.56	12.17
8-15 0207-0253	46	OUTLET	1.82	101.080	0.3435	3.40	4.34	2.44

The measured overall efficiencies remained high at 99.9+% until about hour 42 (8/14) when the measured efficiency dropped to 98.45 and 98.45 again at hr 43. This drop can also be seen in Table I which shows the outlet loadings before 11:00 a.m. 8/14 were generally 0.1 - 0.5 mg/scf, but then increase to 1.1 to 4.1 mg/scf after that time. These higher outlet concentrations are typical of a flaw or failure in the filter element or its sealing.

At 3:00 a.m. on 8/15 the initial test period had been finished and the entire system was shut down.

In the following days the filter vessel was opened and the system was examined. It was determined that several of the heater wires had broken during the test. This had happened in the hottest section of wire nearest the liner, where the 12 awg nickel coated copper stranded wire had embrittled badly under the high partial pressure of CO, H₂, and H₂S. Another item that required corrective action was the outlet nozzle liner. It had shifted during installation of the vessel head and allowed hot gas to bypass this section and had caused a small hot spot (350°F) at the penetration of the outlet nozzle on the vessel head.

When the filter element itself was removed (Figure 6) it appeared to be in relatively good shape, although there was some accumulation of dust at the bottom of the filter, indicating that cleaning could have been somewhat more forceful. After the filter had been brushed off, the outer face looked to be in excellent condition (Figure 7) however, a close inspection of the inner face (closest to the clean gas plenum) revealed a fracture along the flanged surface of the filter. When the filter was removed from the mount, it was seen that the entire inner flange had broken (Figure 8) and had allowed some of the gasket material under that section to be blown out during pulse jet cleaning (Figure 9). This allowed the small amount of penetration that been observed to occur.

Figure 6 - Cross Flow Filter WCXF2 As Removed From METC Test Facility AFTER Initial 50 hr Run

Figure 7 - Cross Flow Filter WCXF2 Brushed Off After Initial
50 Hour Exposure in METC Test Facility

Figure 8 - Photo Showing Failure of Flange on Cross Flow Filter
WCXF2 After 50 Hour Exposure in METC Test Facility

Figure 9 - Photo Showing How Gasketing Material Allowed Some Particulate Penetration After Flange Failure of Cross Flow Filter WCXF2

This type of filter failure was particularly unfortunate since it could have been avoided.. The flange on this filter (WCXF2) had started out at a thickness of 0.5 in, but was reduced to about 1/2 that value when the sealing face was ground smooth for mounting. This element had been returned to Coors prior to use, so that back face and flange could be coated with a "slip" of the parent material and then refired at a high temperature for improved delamination resistance. After this process the front flanged sealing surface was again ground smooth and flat and reduced in thickness to the tested value of about 1/8 inch. It is our feeling that the flange probably was cracked during the mounting of the filter and it subsequently broke after about 65 pulses in the system.

The following steps were taken to remedy the problems observed in the filter vessel. 1) The outlet nozzle liner was repositioned to eliminate the hot spot, and this area was repainted with blue, temperature sensing paint. 2) The multistranded nickel coated copper wire was removed and single strand 12 awg nickel manganese wire was ordered to replace the damaged wire. 3) The Coors filter WCXF4 was prepared for mounting and subsequent test. This filter, shown in Figure 10, had been dipped in a slip and then high fired at 1530°C. The slip material was too thick, in Coors personnel's estimation, to have substantially infiltrated the surface of the filter, with the consequence that most of the coating resided at the surface of the filter where it was not of maximum benefit. It was felt, however, that the high firing should have improved bonding, and the flanges on this element remained at nearly the full 1/2 in thickness.

The new filter element was tested at ambient temperature to determine its virgin pressure drop/flow characteristics. Figure 11 presents this data, where it can be seen that the

Figure 10 - Second Cross Flow Filter (WCXF4) to be Tested at
METC HTHP Gasifier Test Facility

Figure 11 - Cross Flow Filter WCXF4 Pressure Drop vs Filter Face Velocity for Element Never Having Been Exposed to Dust

clean filter pressure drop is about 16 in. wg. at a face velocity of 11.7 ft/min. This is somewhat higher than previous Coors filters and probably is a result of some loss of pore size/porosity during the higher temperature firings.

A decision had been made to install a natural gas fired combustor at the electric process heater outlet to act as a back up heater. The design, fabrication and installation of this device coupled with the Labor Day Weekend precluded any further testing during August.

Cross Flow Filter Testing During September:

On 9/9 the Westinghouse test engineer and technician returned to the METC test site and repaired the internal heater lead wires and proof tested the heater system. During this check out it was determined that the 3 phase power leads to the test vessel had not been properly installed with the result that only one phase had been available. Site electricians corrected the problem and the heaters checked out OK.

The new cross flow filter WCXF4 (shown in its mounting in Figure 12, was installed in the vessel and METC personnel replaced the top of the housing and torqued it down in preparation for pressure checking.

In the preceding week, METC personnel had completed the installation of a small natural gas fired combustor at the outlet of the electrical system process heater to provide additional temperature as required.

Figure 12 - Cross Flow Filter WCXF4 in Mount Prior to
Test at METC

9/10 - 9/11

On 9/10 at 7:45 a.m. the system was begun to be heated on N₂ flow and the electrical process heater. Initial conditions were as follows:

Flow	447 scfh
Temp	400°F
Pressure	100 psig

The resulting filter pressure drop was about 2.8 in wg at 1.8 ft/min. Some difficulty was experienced in subsequent efforts to boost the system gas temperature with the methane fired combustor because of difficulty in getting the methane heater lit. By about 2:15 p.m. the methane combustor was operating in a stable fashion and efforts proceeded with the heat up of the filter system up. At this time the system conditions were:

Flow	1150 scfh N ₂
Temp	350°F
Pressure	80 psig

The filter pressure drop at this point in time was measured at 5.3 in wg at a filter velocity of about 4.5 ft/min. The system was gradually heated to higher temperatures throughout the afternoon. At 5:30 p.m. the temperature was 920°F at a flow of 2280 scfh. From this point until 12:00 midnight the nitrogen flow was gradually reduced to the planned test flow of about 1050 scfh. At 12:00 midnight the process gas was brought on line at a flow of 1050 scfh at 250 psig with the temperature at 927°F which was as high as could be obtained. The initial pressure drop across the filter was about 4 in wg.

Figures 13 and 14 present the pressure drop data for the next 48 hours of operation. As can be seen, the first cycle was of a very long duration lasting 10-1/2 hours. During this time the filter pressure drop rose from 4 to 14.3 in wg. During this time the inlet samples indicated dust concentrations that ranged from 875 to 1900 ppm, and the filter velocity was 2.75 ft/min. The filter was pulse jet cleaned back to the baseline pressure drop of 4.0 in wg. As can be seen in Figure 14 subsequent cycles were somewhat shorter in duration, as is always the case with a new filter in the conditioning stages. Except for the initial sample, efficiencies were seen to remain fairly constant at about 99.5 - 99.8%.

Testing continued in a smooth fashion throughout the remainder of 9/11 until 11:45 p.m. (hr 23.5) when the ignitor on the gas combustor blew out of its fitting, thereby forcing a system shutdown. By the time the system was ready to come back on line the gasifier developed a clinker and this period of test was shut down for the next several days.

9/16 - 9/17

By Monday 9/16 the required repairs to the system had been carried out and the system preheat was started. By 4:00 pm. the filter temperature was at 625°F with 1000 scfh of N₂ at 250 psig. The filter pressure drop was 3.5 in wg. The electrical process gas heater had been taken off line and all of the gas boost heating was being provided by the new gas direct fired heater. System temperature was gradually brought to about 1200°F by 5:30 a.m. on 9/17 at which time the process gas was brought on (Time = 24 in Figure 14). With process gas on and a typical inlet concentration of 450 ppm the pressure drop rose gradually from about 6 in wg to 10 in wg at 1:30 p.m. (hr 31). At this time one of the flexible hose connections in the process gas line failed at a flange weld, and the system was forced off line for a short period for repairs.

— Cross flow WCXF-4 (9/11/85) $T = 1200^{\circ}\text{F}$, $P = 250$ psig, $V_f = 2.74$ ft/min.

Figure 13 - Cross Flow WCXF4 (9/11/85)

Curve 750888-C

- Crossflow filter WCXF - 4 (9/17 - 18/85) $T = 1200^\circ\text{F}$, $P = 250 \text{ psig}$

Figure 14 - Cross Flow Filter WCXF4 (9/17-18/85)

By 5:15 p.m. the N₂ flow was back on at 910 scfh and the temperature was 422°F with a system pressure of 110 psig and a filter differential pressure of 5.3 in wg. By 10:30 p.m. that evening the system was returned to process gas flow at 1150 scfh and as indicated by the trace at hour 31, Figure 14, the pressure drop cycle was continued at the point at which it was interrupted. At 2:45 a.m. 9/18 the ninth cleaning pulse to WCXF4 was administered as the pressure drop had risen to 15.1 in wg. At a flow of 1150 scfh the base line pressure drop was established at about 7.5 in wg. At this time the flow was brought to 1200 scfh or a velocity of about 3.2 ft/min.

Over the next seven hours testing proceeded smoothly with a pressure drop cycle of 8.5 to 16 in wg over roughly 90 min periods with inlet loadings of about 300 ppm. At 10:00 a.m. (hr 42.5) the system flow was increased to 1400 scfh (velocity of 3.7 ft/min). The baseline pressure drop was seen to increase proportionally to about 10 in wg. Over the next several hours and cycles testing generally went smoothly, however, there were several unexplained bumps in the pressure drop traces (hr 42.5, 44.7, 46, 47). The nature and cause of these spikes is not known. At 3:00 (hr 48) the filter was cleaned with a series of three pulses, the first being a standard 300 psig reservoir, which the second two were from a 350 psig reservoir. Some improvement in cleaning was realized with the higher pressure pulses as the baseline was driven down to 5.3 in wg.

At 4:00 p.m. on 9/18 the planned 50 hr run on desulfurizer gas was completed and the system was switched back to straight coal gas. In this process a plug occurred in the flow control valve and caused a short excursion in the system. At 7:40 p.m. the process gas was brought back on line and the filter experienced a sharp spike in pressure drop to 42 in wg (Figure 15). The filter was immediately pulse cleaned and the

Figure 15 - (9/18/85) 19:30 to 22:00 Hrs WCXF4

pressure drop returned to 12 in wg. With the system nominally at 1750 scfh, 1400°F and 250 psig the base differential pressure was approximately 12 in wg. Over the next 2-1/2 hours the filter operated between 12 and 30-32 in wg in a relatively stable fashion. At 10:00 p.m., however, the sampling system developed a problem as it became overheated and began to sag. This caused an immediate shut down for repair.

Since the system was down a decision was made to modify the combustor system so that it could provide all of the heating required to achieve a 1600°F filter temperature (previous runs could only reach 1400°F max.). It was also decided that the test vessel should be moved closer to the heater outlet in order to avoid some of the temperature drop previously experienced between the combustor outlet and filter inlet. These modifications precluded any further testing in the month of September.

Since the system was going to be down for a period of a few weeks, and since some constant penetration had been observed throughout the test, a decision was made to open the vessel and inspect the filter element.

The element "as removed" appeared to be in pretty good condition and is shown in Figure 16. After some cleaning, however, it was observed that a delamination had occurred with the crack crossing the back face of the filter as shown in Figure 17. Since such delaminations usually only cause leaks at the crack at the front sealing face, and since we did not have any clearly superior filters available, and since we wanted to accumulate significant test time on one element, we made a decision to plug the corrugation through which the leak was thought to be occurring and to proceed with the test using this element. Figure 18 presents a photo of the repaired element prior to installation in the vessel.

Figure 16 - Cross Flow Filter WCXF4 AS Removed from METC Test

Figure 17 - Cross Flow Filter WCXF4 Brushed Clean After METC
Test Shows Crack Through Back Wall

Figure 18 - Cross Flow Filter WCXF4 After METC Test Showing Patch at Clean Face Channel

Design Principles Testing

In support of the test work at METC and the conceptual design task that is part of this program, we are carrying out a design principles task. The overall goal of this task is to develop scaling techniques which will allow us to extrapolate the data gained in previous tests and from the testing of the cross flow filter at the METC gasifier to large commercial scale systems. Since filtration systems are basically modular in nature, scaling of most of the associated systems is straight forward with the exception of the blow back system. Commercial embodiments of the cross flow technology will most certainly consist of many filter elements mounted on a common manifold to form a single module. During a pulse jet cleaning of a module, many filter elements (operating in parallel) must be cleaned at once. This represents a significant departure from all of the experimental work carried out to date, since all previous work has been done on single, relatively small filter elements.

Our Design Principles Test program has been directed at firming up this area of endeavor in the following manner:

- To upgrade an existing computer simulation of the pulse jet cleaning event and to transfer this model to a more accessible and economic PC environment.
- To conduct pulse jet cleaning experiments at ambient conditions on a full scale cross flow filter simulator. These tests measure the cleaning pulse pressure rise generated by the blow back system as a function of design and operating parameters such as pulse reservoir pressure, nozzle size and position, valve characteristics, plenum and venturi geometry and filter resistance.

- We will then use the full scale, but ambient condition, pulse rise data to calibrate parameters in the computer model of the cleaning event. This would include determination of optimized values for parameters such as pressure expansion loss coefficients and venturi effectiveness factors.
- In parallel, experiments were carried out that attempted to determine the adhesive forces between various dust cakes of interest and the filter surface, since the cleaning pulse must generate enough force on the dust cake to dislodge it from the filter surface. Since it was anticipated that these adhesive forces would be strong functions of temperature, provisions were made to carry out these tests at elevated temperatures.
- Having accomplished these tests we would be able to project valid designs for the full scale commercial HTHP cleaning systems required of the conceptual design study portion of this program.

The following discussion expands a bit on each aspect of the efforts mentioned above.

Computer Model Upgrade:

The actual computer model used to project the dynamics of the cleaning sequence was developed in a previously DOE sponsored Cross Flow Filter development program, and is described in detail in the final report resulting from that project (Hot Gas Cleaning Using Ceramic Cross Flow Filters DOE DE-AC21-79ET15491). As part of the current program we

established the goals of transferring the code from our main frame computer to the more easily and widely accessible and economic IBM PC-XT format, and then implementing several improvements to the program. The code was transferred to the PC format without too much difficulty, which made work on the upgrades somewhat easier. During this process it became clear that the critical component of the model (the eductor portion) would be even easier to work on if it were removed from the overall code and made to stand alone. After expending a reasonable amount of effort on this task we were unsuccessful and we abandoned this effort. We resorted to running the entire program even when only the eductor portion was all that was required.

The specific improvements incorporated in the model are:

- 1) Inclusion of the pressure rise term due to gas deceleration upon expansion out of the module into the clean gas side of the tube sheet. Previously the model had only accounted for the irreversible pressure loss due to the abrupt clean gas expansion.
- 2) Inclusion of all of the velocity change terms in the total energy balance equation that is used to calculate the mixed gas temperature (induced, pulse and filtered). previously simplifying assumptions ignored the kinetic effects of the induced and filtered gas terms.
- 3) Inclusion of a calculation method that allows the pulse solenoid valve to be modeled with a finite opening time. Previous computations assumed the valve opened instantaneously.

Full Scale Ambient Pulse Tests:

The details of the actual ambient pressure and temperature pulse test system are presented in the previous quarterly report along with the data produced in the initial series of tests. What has been done is to construct a full scale mounting plenum and fit the plenum with porous metal plates that simulate the presence of actual cross flow filters. The use of actual cross flow filters was not possible because full scale (12 x 12 x 4 inch) elements do not exist at this point in time and would be very expensive to fabricate for these tests. Additionally, we feel the simulation provided is a good and valid one, based on the following reasoning.

It was desired to simulate the pressure drop response to flow of a cross flow filter using another porous media. For the simulation to be true the porous media must, therefore, offer the same pressure drop at a given flow as does the cross flow filter. This can be achieved by varying the porous media's resistance (porosity and thickness) and its area. The pressure drop for the cross flow filter can be expressed in terms of its volumetric flow Q , its filter area A_{xf} and its resistance R_{xf} as follows:

$$P_{xf} = (Q/A_{xf}) R_{xf}$$

Similarly the simulator pressure drop response to the same flow can be expressed as

$$P_s = (Q/A_s) R_s$$

Since we want the same pressure drop response to a given flow Q we get the following expression:

$$R_{xf}/A_{xf} = R_s/A_s$$

Since we expect a full scale (12 x 12 x 4 in) cross flow filter to have about 15 sq. ft. of available filter area $A_{xf} = 15$. In our test rig the cross flow simulators were distributed along the length of the plenum just as we expect they would be in a real system. They are mounted in the same rectangular orifice (12 x 4 in) that a cross flow filter would be. Therefore the area of the simulator is fixed at

$$A_s = 12 \times 4 \text{ in}^2 = 1/3 \text{ ft}^2.$$

The resistance of the simulator can be found as

$$R_x = (A_s/A_{xf})R_{xf} = R_{xf}/45$$

From previous experience and we expect that the pressure drop of a conditioned cross flow filter will be about 15 in wg $\sim 1/2$ psi at a filter velocity of 10 ft/min.

$$R_{xf} = (1/2)/10 = 1/20$$

This implies that the simulator resistance should be

$$R_s = R_{xf}/45 = 1/900 = .0011$$

Figure 19 presents the pressure drop characteristics of standard, stock porous sintered metal sheets of varying pore size. It can be noted that the 40 μ material has a pressure drop of 1 psi at a velocity of 960 ft/min or a resistance

$$R_s = 0.00104$$

which is very close to what was calculated to be required. We have, therefore, utilized this material as the media for simulation of the cross flow filters. Additionally we have investigated the effect of varying dust cake thicknesses by sandwiching layers of porous polypropylene sheet in the system. The incremental resistance adds in series just as dust cake would in a real system.

Figure 19 - Pressure Drop vs Velocity for Porous Metal Plate

Correlation of Ambient Pulse Tests with Computer Model:

To date we have completed one series of pulse rise measurement tests as reported in the Third Quarterly. Because of limited access to the engineer that has carried out the modeling, we have only exercised the improved model against one of the experimental test runs. The conditions for this test run were as follows:

Pulse Reservoir	400 psig
Nozzle Diameter	0.75 inch
Pulse Duration	0.2 seconds
Induced Flow	Allowed
Simulated Filter Cake	None

The actual observed pulse rise was uniform along the length of the plenum and was measured at approximately 1.3 psi maximum. Without adjusting any of the model parameters the calculated pulse rise was determined to be 0.85 psi. We are generally pleased with this degree of agreement. Our intention is to confirm the model's ability to track trends in peak pressure rise as a function of the other pulse parameters, and then to adjust model parameters to obtain the best agreement possible between the measured and calculated results.

When this has been completed we feel we will be able to have some degree of confidence in projecting HTHP conditions for scale up purposes.

Dust Cake Adhesion Testing:

AS reported in previous technical status reports, we have completed a preliminary set of dust cake adhesion tests with Pressurized Fluid Bed Combustion dust and with gasifier

char obtained from the KRW pilot scale gasifier (see Figure 20 for size distribution of the char dust). Table 2 summarizes the series of tests that had been completed. We have begun to assimilate and compile the data from these tests and have prepared a series of pressure drop/flow curves for the tests run to date. Figures 21 to 27 present the reduced data in graphical form. The pressure drop behavior anticipated was, in fact, observed in the ambient testing, but is much less obvious in the high temperature tests. We are currently analyzing the data and are in the process of deciding whether or not to pursue the tests any further.

No further work has been done on this task this quarter, however, it was interesting to note that the task's general conclusion that gasifier char should be much easier to pulse jet clean from the filter, has been borne out by the testing at METC where very gentle pulse jet cleaning programs have proved to be successful.

Filter Element Supply and HTHP Testing:

Coors:

As reported in June the first Coors flanged cross flow filter had been tested at HTHP and had worked very well for a short time, and then failed by delamination. This unit was returned to Coors for them to examine and test. During this time Coors personnel undertook a short test program to systematically explore the relative effect of several parameters on the bonding problem. In this effort 12 separate runs were made examining the effects of:

Bonding materials - none, 3 different fluxing clays, a mortar and a slip (dilute suspension of the parent material)

Weight loading during firing - weighted/unweighted

Firing temperature - 1520 to 1530°C

Figure 20 - Particle Size Distribution for KRW Char Used in Dust Adhesion Tests

Table 2
DUST ADHESION TESTS SUMMARY

<u>Test Date</u>	<u>Dust Type</u>	<u>Comments</u>
6/12-1	Char Fines	Dust cake starts to lift and crack at
-2	"	pressure drop of .04 in wg at velocity
-3	"	of about 2 cm/min
-4	"	
6/13-1	Char Fines	Cake compressed with high downflow at
-2	"	415 cm/min and 9-10 in wg. Did not
-3	"	change velocity or pressure drop at
-4	"	which cake lifts and cracks
6/14-1	PFBC Ash	PFBC ash cake compressed at 725 cm/s
-2	"	and 32 in wg. Pressure and velocity at
-3	"	which cake lifts much higher than char.
-4	"	$\Delta p = .7 - 1.0$ in wg and velocity = 25 - 30 cm/min.
6/21-1	Char Fines	Test carried out in 4 cell assembly in
-2	"	furnace but at ambient temp. Cell 1 was
-3	"	disturbed during installation. The
-4	"	pressure drop and velocity break about 3-4 cm/min and .04 - .05 in wg.
6/25-1	PFBC Ash	Test carried out in 4 cell assembly in
-2	"	furnace at ambient temperature. Cell 1
-3	"	was the only unit that displayed a
-4	"	break in Δp curve at expected velocity/ pressure drop. Installation may have disturbed dust cake layer.
6/26-1	Char Fines	Test carried out in 4 cell assembly in
-2	"	furnace at 815°C. Were unable to
-3	"	discern any breaks in pressure drop
-4	"	curve
6/28-1	PFBC Ash	Tests carried out in 4 cell assembly in
-2	"	furnace at 815°C. Only Cell 3 showed
-3	"	a break in pressure drop behavior. The
-4	"	others did not exhibit clear change in Δp curves.

Char Dust Adhesion Test (6/26/85)

Four Cell Assembly At 815 C

Char Dust Adhesion Test (6/26/85)

Four Cell Assembly At 815 C

Figure 21 - Char Dust Adhesion Test at 815°C in Four Cell Test Assembly

Fig 6 Char Dust Adhesion Test (6/13/85)

Figure 22 - Char Dust Adhesion Test at Ambient Conditions (6/13/85)

Fig 7 PFBC Dust Adhesion Test (6/14/85)

Figure 23 - PFBC Ash Adhesion Test at Ambient Conditions (6/14/85)

Char Dust Adhesion Test (6/21/85) Four Cell Assembly At Ambient Temperature

—□— Cell 2
—x— Cell 3
—▽— Cell 4

Figure 24 - Char Dust Adhesion Test at Ambient Conditions in Four Cell Test Assembly (6/21/85)

PFBC Ash Adhesion Test (6/25/85)

Four Cell Assembly At Ambient Temperature

PFBC Ash Adhesion Test (6/25/85)

Four Cell Assembly At Ambient Temperature

Figure 25 - PFBC Ash Adhesion Test at Ambient Conditions in Four Cell Test Assembly (6/25/85)

Char Dust Adhesion Test (6/12/85-3)

T = 25 C, P = 1 atm

Char Dust Adhesion Test (6/12/85-4)

T = 25 C, P = 1 atm

Figure 26 - Char Dust Adhesion Test at Ambient Conditions (6/12/85)

PFBC Ash Adhesion Test (6/28/85)

Four Cell Assembly at 815 C

PFBC Ash Adhesion Test (6/28/85)

Four Cell Assembly at 815 C

Figure 27 - PFBC Ash Adhesion Test at 815°C in Four Cell Test Assembly

The preliminary conclusions drawn from this work were that higher firing temperatures and the use of a slip to infiltrate the back wall of the ceramic body appeared to be the best near term bet for improvements of the bonding and resistance to delamination. Longer term developmental approaches would include modifications to the mechanical design of the joint between adjacent layers of the body.

Concurrent with this work, it was discovered that a mistake had been made in the formulation of the powder that was to be the starting material for new filter bodies for test. This was a problem because there would not be enough time to reformulate a new batch of starting material before testing was scheduled to begin at METC. After some scouting around enough material from previous programs was found to machine two more 6x6x2 filter elements. The filter layers were machined and prepared for firing. At this time Coors personnel also thought that since the delamination of the first filter tested had been so clean, it would be possible to refire the element and rebond the delaminated sections. One of the newly machined elements and the element being repaired were first infiltrated with a slip of the parent material at the back wall and front flange and then they both were placed in the kiln together for the firing process. Unfortunately the PFBC dust remaining in and on the tested unit (being mainly silica) fluxed the body at the high firing temperatures and caused it to slump. In doing so, it interfered with the new unit and pushed it over into a curved shape. Figure 28 presents a photograph of the two elements as they appeared after the firing.

The second (and last) new filter assembly was then infiltrated with the slip and placed in the furnace for its firing schedule. This element was fired at the highest temperature possible without risking slumping (1530°C).

Figure 28 - Cross Flow Filters WCXF1 and WCXF3 Slumped During Firing
Because of Included PFBC Ash

As can be seen in Figure 29 this process proved successful. The flanges of this unit are considerably thicker and more rugged than either of the two initial units supplied. This unit was shipped to us and was available for testing either here or at the METC site.

After successfully demonstrating the ability to fire the elements at the higher firing temperature with the back and flanges infiltrated by the slip material, we decided to risk the process on the second, unused, element of the first pair fabricated. This unit was shipped to Coors where they dipped the back and front flange in the slip, and then refired the unit at the higher firing temperature. This process was successfully carried out and the resultant unit is shown in Figure 30.

In August personnel at Coors began preparing a new batch of raw material from which they were to press new plates for subsequent fabrication into new 6 x 6 x 2 test filters. Their goal was to have new units in time for the early September restart of testing at METC. We had also agreed to attempt destructive testing of the elements mounted in the HTHP test rig at Westinghouse in an attempt to quantify the blow back burst pressures of the filters in actual use. Late in August the plates were pressed and the tiles were machined into cross flow filters. Unfortunately during the firing of the filters two problems were encountered. The first arose from the fact that the binder used for porosity control had not been ground fine enough so that the fired parts had many sizable voids distributed throughout the body. Secondly, with the high firing temperatures and the two firing processes one of the two bodies slumped and the second one developed a ripple in the top sealing layer. In spite of these problems the ribbed element (WCXF5) was shipped to Westinghouse and received on a Saturday, 9/7/85, before the scheduled 9/10 start date for

Figure 29 - Cross Flow Filter WCXF4 Successfully Fired at High Temperature
With Slip Coating on Front and Back Face

Figure 30 - Cross Flow Filter WCXF2 Successfully Refired at High Temperature after Slip Coating on Front and Back Face

testing. After examination of the element it was decided to use the WCXF4 filter element for the next test sequence. The newly received element WCXF5 was prepared for possible use by patching with ceramic adhesive and grinding the back side of the flanges so they were even with the front sealing face. Figure 31 presents a photo of this element. The clean pressure drop characteristics of the element WCXF5 were determined and are presented in Figure 32. It can be seen that the pressure drop trace is somewhat higher than previous cross flow elements which is an indication of loss of porosity and pore size due to the high firing temperature, and times. This development has been discussed with the Coors personnel and they are investigating the effect.

Ceramic Sealing/Mounting Springs from Coors:

In a completely different area, Westinghouse personnel had enquired if Coors could use their expertise in ceramics to fabricate a ceramic spring to aid in the common difficulties experienced in mounting ceramic filters of all natures in metallic tube sheets and mounting plenums. It is our belief that the development of such a spring loaded system could better accommodate the problems of differential thermal expansion, high temperature yielding of bolted joints and finally be more able to perform in the potentially corrosive atmospheres typical of advanced coal conversion technologies. After some consultation with DOE project personnel it was decided that a small task to investigate this interesting possibility was within the scope of work defined for the project. Accordingly, Westinghouse provided Coors with a first cut at a specification for a ceramic spring and Coors proceeded to fabricate the first pair of springs to these specifications. The initial pair of springs were ground from existing alumina tube and one is shown in Figure 33. These springs were ground from a 60 mm OD by

Figure 31 - Cross Flow Filter WCXF5 Shown Patched, With
Flanges Ground Parallel. Note Ripple at Top Layer

Figure 32 - Cross Flow Filter WCXF5 Pressure Drop vs Filter Velocity in Unused Clean State

Figure 33 - Ceramic Mounting Spring Fabricated From Alumina Tube and Usable at Temperatures Up to 900°C

Force/Deflection for 900 C Filter Mounting Spring

Alumina, 60 mm Dia, 75 mm Long, 6 Turns, 8X9 mm Cross Section

Figure 34 - Force Deflection Curve For Ceramic Mounting Spring

45 mm ID alumina tube. The spring is approximately 75 mm in length and has 6 turns including the end turns that are ground to allow the ends to be flat. Upon receipt of the springs Westinghouse performed a standard deflection vs force test on the units. The results of this test are presented in Figure 34 and indicate that the effective spring constant is 134 N/mm or (750 lbf/in). The actual spring constant is about what one would calculate from standard spring formulas based on the shear modulus of alumina and the dimensions of the spring. One of the springs was tested to failure in order to determine the maximum deflection that could be expected from that design. This spring reached a deflection of 6.1 mm (0.24 in) before failing. It is considered to be a fairly easy task to design the spring to have a lower constant and more deflection now that a reference spring has been established. As indicated in the Filter Testing Section, we have had the opportunity to successfully test the remaining spring at high temperature and pressure with a cross flow filter. Having had the opportunity to test these springs we prepared a second set of specifications for the next set of springs to be fabricated by Coors.

We used standard spring formulas* to analyze the force/deflection characteristics of the ceramic springs that Coors have provided. The following formula has been found to be quite good in predicting the performance of helical, rectangular cross section springs.

$$S = \frac{2 PR^3N}{Ga^3} \left[\frac{1}{b/3 - .209a[\text{Tanh}(a/26) + .004]} \right]$$

* Roark, R. J. "Formulas for Stress and Strain", 4th Ed., McGraw-Hill (Pg 209)

where

S = Compression (in)
P = Force (lbf)
R = Radius of Spring (in)
N = Number of Turns
G = Shear Modulus (psi)
a = Smaller dimension of cross section (in)
b = Longer dimension of cross section (in)

Using this formula, we provided dimensions for Coors to make a second pair of springs that were to have a force of 50 lbf at a deflection of 0.25 in. The springs shown in Figure 35 were tested in our mechanical test labs and found to have a force of 48 lbf at a deflection of 0.25 in.

GTE Sylvania:

During July we received two sets of three filters from GTE all with dimensions of 6x6x2 inches. These filters all incorporated the new "double high" end sealing design. The first set received July 9, had been formulated with an acicular organic filler which personnel at GTE felt led to an anisotropic pore structure and consequently to poor porosity. These filters were examined visually and did not seem to be bonded very well. In fact one of the elements could be easily delaminated by simply pulling the unit apart. Figure 36 shows one of the units. We have outlined an adjacent pair of plates to indicate the newly developed design for back face closure and sealing. The best looking element was chosen and prepared for testing in the HTHP test rig, since we were anxious to have at least a little test experience with the GTE material prior to committing to the filters to be tested at METC.

Force/Deflection for 900 C Filter Mounting Spring

Alumina, 60 mm Dia., 75 mm Long, 6 Turns, 4.7X9 mm Cross Section

Figure 35 - Second Set of Ceramic Filter Mounting Springs
50 lbf (222.4 N) at 0.25 in (6.3 mm) Deflection

Figure 36 - GTE Cross Flow Filter Element Showing New Back Face Sealing Method and Resultant Cracks at Back Face

Since this set of filters did not have integral flanges, we attempted to provide the functional equivalent by forming small clips from Kanthal heater wire and inserting these clips through all the channels at the front face of the filter. Figures 37 to 40 illustrate the manner in which the clips were inserted and how the unit was finally installed in the horizontal support plenum assembly.

On July 23 the filter had been installed in the HTHP test facility and the first set of tests on GTE materials was initiated. The first step was to determine the ambient conditions, clean base line pressure drop by flowing cold air through the system and recording the pressure drop. Figure 41 presents this data, and it can be seen that the resistance to flow of the GTE material was very much higher than expected. At a filtering velocity of only 4.5 ft/min the pressure drop was 17.5 in wg, whereas the Coors filter media was only 0.25 in wg at the same velocity. After establishing the base line pressure drop the system was brought to a temperature of 1000°F and a pressure of 150 psig. The pressure drop trace for this test is presented in Figure 42. Because the resistance of the filter was so high the system flow was limited to 120 lbm/hr which yielded a filter face velocity of approximately 6.5 ft/min. At these conditions the filter pressure drop started at about 55 in wg and climbed to 75 in wg in 30 minutes when exposed to roughly 7500 ppm of PFBC dust during the first cycle. At this point the filter was cleaned with a series of pulses from the reservoir pressurized to 250, 300 and finally 350 psig. The base line pressure drop was returned to nearly its original value and a second cycle was initiated. During this cycle some difficulty was experienced with the dust feeding system and the pressure drop curve was much flatter. The second cleaning sequence was initiated at a pressure drop of

Figure 38 - GTE Cross Flow Filter In Mount Without Retaining Flange

Figure 39 - Close Up of Mounting Clips After Retaining Flange Had Been Installed and Tightened

Figure 40 - Fully Assembled GTE Cross Flow Filter Prior To Installation in HTHP Test System

Figure 41 - Pressure Drop vs Filter Velocity For WGTE6 in Clean State

Cross flow filter WGTE6 (7/23-24/85): $T = 1000^{\circ}\text{F}$, $P = 150$ psig, $C = 6600$ ppm, $V_f = 6.5$ ft/min, $\eta = 99.7\%$

Figure 42 - Pressure Drop vs Time for WGTE6 Cross Flow Filter
(7/23-24/85): $T = 1000^{\circ}\text{F}$, $P = 150$ psig, $C = 7500$ ppm, $V = 3$ ft/min

75 in wg and it consisted of a single pulse from a 350 psig source. This dropped the base line pressure drop to a value of 50 in wg which was somewhat below the initial value of the day. This coupled with the facts that the ensuing pressure drop rate of rise was very slow and the fact that significant penetration was beginning to be observed led us to suspect that the filter had failed. On 7/24 the system was brought back to the previous day's test conditions and one additional cycle was carried out. The initial base pressure drop was at a value of only 35 in wg and rose very slowly while significant dust penetration continued. In view of these facts the test was aborted and the system was allowed to cool so the filter could be removed for inspection. When the filter was removed it could be seen that the thin top end plate had cracked as shown in Figure 43. It was also determined that leaking had occurred at spots in the back of the filter where the new end sealing method had left cracks open to the clean gas side of the filter. Overall the filter looked quite good with the suspect layer to layer bonding surviving quite well. The end plate is very much thinner than any other section of the unit and could conceivably be made thicker and stronger. The end seal cracks occur when the unit is fired and the plates with the long channels shrink away from the end surface. It seems to be a simple matter to effectively plug these leaks with an appropriate adhesive.

When the second set of filters was received from GTE they appeared to be somewhat better bonded and appeared to be more porous. These elements were formulated with a uniaxial organic filler and were reported to possess more uniform porosity. Figure 44 presents a photograph of one of the units received in this shipment. This element was prepared for test in a manner similar to the previous GTE filter with the exception that this filter was "caulked" with Aremco ceramic adhesive in order to prevent leaking thorough the end

Figure 43 - Failed GTE Cross Flow Filter Element

Figure 44 - GTE Cross Flow Filter (WGTE9) Formulated With Uniaxial Organic Filler

plate seal cracks. The unit was installed and sealed in the mounting assembly and placed in a 200°F oven overnight to partially cure the patching adhesive. Examination of the unit just prior to installation revealed that the filter had delaminated at some point in the mounting or curing procedure as can be seen in Figure 45. Upon careful examination it appeared that the failure had occurred because nonuniform pressure had been exerted on the element during tightening of the flanges on the wire clips.

At this point in time we had received and tested the first pair of Coors ceramic springs and it seemed to be a good idea to try an experiment with the concept of spring loading a cross flow filter. Fortunately the existing mounting jig made this exceptionally easy to do. As indicated in Figure 46 one of the GTE filters was simply placed on an Interam mounting gasket and then pushed into the gasket by the ceramic spring which was placed on the back wall of the filter and compressed by a simple threaded stud which was passed down through the mounting plate. This arrangement allowed for a very accurate measurement of the spring deflection and consequent sealing load. The spring was compressed 2.8 mm (0.11 in) and exerted a downward force of approximately 80 lbf. The assembly was mounted in the HTHP test rig and prepared for test.

Cold flow testing of the filter revealed the fact that these filters had an even higher pressure drop than the previous set of filters. Figure 47 presents a plot of the pressure drop vs flow data for the clean GTE filters. After the cold flow testing was completed the system was brought to a temperature of 1000°F and a pressure of 150 psig. The test air flow was set at 120 lbm/hr for a filter face velocity of 6.5 ft/min. Because of the very high pressure drop both the local gauge and the differential pressure transmitter usually used to record filter pressure drop were over scale. A temporary digital display and transducer were

Figure 45 - GTE Cross Flow Filter (WGTE9) Delaminated During Mounting Process

Figure 46 - GTE Cross Flow Filter (WGTE10) Mounted and Sealed Using Ceramic Spring

Cross Flow WGTE10 No Exposure to Dust

T=70 F, P=0 psig

Cross Flow WGTE10

T=1000 F, P=150 psig, C=9800 ppm, V=6.5 ft/min

Figure 47 - GTE Cross Flow Filter (WGTE10) Pressure Drop Characteristics at ambient conditions and at HTHP Conditions with Dust

installed and it was determined that the filter pressure drop was about 11.5 psi (320 in wg). Dust feed was initiated and the pressure drop increased to approximately 370 in wg over a 8 min period with a dust loading estimated at 9,800 ppm as shown in Figure 47. Attempts were made to blow back the filter at pulse reservoir pressures of 250, 300 and 350 psig, with the bypass closed and then open. Little if any pressure drop recovery was observed during the 300 and first 350 psig pulse. The second 350 psig pulse was administered with the system bypass opened and the pressure drop immediately dropped to less than 10 in. wg. Assuming that the filter had been broken the test was halted and the system allowed to cool for inspection.

Subsequent examination of the filter the next day revealed the fact that the filter had not actually failed, but that the sealing gasketing material had been blown out in several places and that several of the back face cracks that had been patched with adhesive had been blown open allowing free inleakage to the filter as shown in Figure 48. The ceramic mounting spring was in place providing substantial sealing force in spite of the fact that a small piece of the spring had broken at the top of the spring where the cross section of the spring had been ground down in order to provide flat parallel surfaces. We feel that this preliminary test certainly provides incentive for further investigation of the spring loaded concept.

In late September GTE shipped three 6 x 6 x 2 filters with no flanges and one part that was intended to demonstrate their ability to make flanged elements. One of the three filters without a flange and the flanged part are shown in Figure 49. The unflanged filters (WGTE 12, 13 and 14) were intended to have higher porosity and lower pressure drop. Although the sides required some patch work because of some

Figure 48 GTE Cross Flow Filter After HTHP Testing Showing Blown Out Gasketing and Ceramic Adhesive Patches

Figure 49 - Cross Flow Filters from GTE - WGTE 14 without Flange and WGTE 15 Demonstrating the Ability to Fabricate Flanged Elements

leaking, the filters were tested in the clean state. Figure 50 presents a plot of pressure drop vs flow for the element WGTE 12. It can be seen that these filters are in fact considerably more porous than the most recent GTE filters (ref. Figure 48), however, they still offer considerably more resistance to flow than we would like to have.

Task 3 - Conceptual Systems Analysis

Because of delays in testing, we have not initiated a large effort in the conceptual system analysis as had been planned. We have received a letter of technical direction from DOE regarding the basis for the systems to be included in the study. In the following we present our intended design approach and our initial response to the proposed base case studies.

3.1 Design Approach Document

3.1.1 Introduction

The overall goal of this task is to assimilate all of the modeling developments and validations testing results for the ceramic cross flow filter in a set of realistic design and cost analyses using the filter technology in three gasification systems; Lurgi/Air, KRW/O₂, and Texaco/O₂. Guidelines provided by R. J. Dellefield on September 9, 1985 will be used to establish system size and configuration, and to prepare complete system investment and cost of electricity analyses.

3.1.2 Scope of Cost Estimating Work

Integrated coal gasification combined-cycle electric power generation systems using ceramic cross flow hot gas filtration with hot gas desulfurization will be costed. The proposed scope of the cost analyses is:

Figure 50 - Pressure Drop vs Velocity for New Unused
Cross Flow Filter WGTE 12

Investment Costs

- * Coal railcar unloading and 30 days storage
- * Coal reclaiming, sizing, and drying (if required)
- * Coal pressure gasification, complete with pressurized coal feeding and ash cooling, depressurization, and removal
- * Coal gas cooling to filtration/desulfurization conditions
- * Hot gas particulate removal by cross flow ceramic filter, with ash cooling and depressurization
- * Hot gas desulfurization by METC zinc ferrite with sulfur recovery by Allied SO₂ reduction to sulfur
- * Hot gas flow control into a Westinghouse combustion turbine system with commercial 251B10 turbines, plus a HRSG and a WECAN condensing steam turbine system.
- * A full complement of support facilities including feed water treatment, cooling towers, waste water treatment, railcar sidings for coal unloading and ash loading, power transmission substation and switchgear, and administration, maintenance shop, laboratory, and control buildings.

Cost of Electricity

For a facility to be constructed in the 1986 to 1990 time frame, the cost of electricity will include:

- * Contingencies for unaccounted for costs
- * Escalation during construction
- * Interest during construction
- * Working capital
- * Depreciation
- * Interest on debt
- * Return on equity

- * Coal, oxygen, water, and ash disposal costs
- * Real estate taxes
- * Federal and state income taxes
- * Catalyst and chemicals costs

Total costs will be reported as mills per KWH of net electric power.

3.1.3 Costing Methods

The ceramic cross flow filter system will be estimated by individual system element, such as Filter, Ash Cooler, Ash Lock Hoppers, Blowback N2 Compressor, Blowback N2 Accumulator, etc. Those cost elements, including estimates for blowback valves, lock hopper valves, safety discs, control sensors and control computer system, etc. will be integrated into a total installed cost including piping, wiring, structure, insulation, etc. for the particulate removal system. Other system elements will be estimated by process unit from pertinent U. S. DOE and EPRI costs for Lurgi, KRW, and Texaco process units. The hot gas desulfurization estimate for the METC zinc ferrite system will be based on work provided to METC as part of the Evaluation of Gasification and Gas Cleanup Processes for Use in Molten Carbonate Fuel Cell Power Plants, Final Report, DOE/MC/16620-1306 Performed under Contract No. AC21-81MC16220.

3.1.4 Hot Gas Cross Flow Ceramic Filter Design Approach

The cost estimate specified in Section 3.1.3 above will be based on the design approach for the cross flow filter system as follows:

Materials selection will be based on refractory lined mild steel pressure containment vessels wherever the temperature of the unlined vessel shell would normally be above 900F. Between 900F and 650F the materials will be chrome/moly alloy steel. Below 650F the materials will be high quality vessel grades of mild steel. The ceramic filter elements will be alumina, specially fabricated for the service. The filter element support tube sheet will be 310 stainless or Incoloy 800.

Safe operation will be assured by the incorporation of a tube sheet bypass rupture disc to prevent failure of the tube sheet with excessive filter element pressure drop. Nitrogen will be used for filter blowback and for instrument sensor purging. Ash will be cooled to below 650F prior to depressurization. The ash cooler and the lockhoppers will also be purged and pressurized with N2. Maintenance access manways and full spectacle line blinds will be provided for filter maintenance access. Inert gas purging and air ventilation of the filter vessel will be provided prior to entry for repair or replacement of filter elements.

Filter module size will be based on the fuel gas flow and fuel gas pressure and temperature conditions specified in the September 9, 1985 letter from Mr. Randall J. Dellefield of METC to Dr. David Ciliberti of Westinghouse Electric Corporation.

Westinghouse R&D Center
1310 Beulah Road
Pittsburgh, PA 15235

September 27, 1985

Mr. R. J. Dellefield, Project Manager
Utilization Energy Systems Branch
U. S. DOE
P. O. Box 880
Collins Ferry Road
Morgantown, West Virginia 26505

SUBJECT: Contract No. DE-AC21-84-MC21338

Dear Mr. Dellefield:

Your letter of September 9 on the subject contract needs clarification of the following items:

Is the 9000 BTU/KWH heat rate on the same net basis as the 100 MWe power output? Is the heat rate on a high (gross) heating value basis? If the answers to both are yes, then we would require $9000 \times 100,000 = 900,000,000$ BTU per hour of fuel gas high heating value as the basis for gas flow from each gasifier.

Table 2 provides a 700K temperature for the Fixed-Bed Gasifier case. Is the gas saturated with tars and oils at that fairly low temperature so that it would need to be superheated to pass through a filter without depositing tar/oil?

The gas pressure for the Fixed-Bed gasifier is given as 101 kPa, which is essentially sea level atmospheric pressure. The gas after passing through a filter, which has some pressure drop, would then be below atmospheric pressure. Is that really your intent?

The gas pressure for the "Typical PFBC" unit is 6080 kPa. That is so high that it must be an error. Likewise, the gas pressure for the Fluidized-Bed Gasifier is given as 507 kPa. That is much too low for use in the combined-cycle systems that we are familiar with. It appears to be a U-Gas, not a KRW fluidized bed gasifier that is used as the basis for Table 2. The U-Gas system has not yet operated at pressures high enough to fuel a combined cycle plant.

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September 27, 1985
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The small Mass Median Size for the particulate matter in the Fixed-Bed Gasifier gas implies that the gas has been cleaned, or that it is from an atmospheric pressure gas producer, not a Lurgi gasifier. The atmospheric gas producers, when operated at low throughput and with their low density gas, might produce such a small dust size but it is not at all typical of Lurgi gasifiers.

We would appreciate your help in clarifying these issues.

Very truly yours,

E. J. Vidt
Advisory Engineer
NTD/Process Engineering

/rmh

*budget and
milestones removed.
ds*

**DATE
FILMED
8 / 17 / 92**