**TIDD PFBC HOT GAS FILTER OPERATING EXPERIENCE
JULY 1993 - APRIL 1994**

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**Tidd PFBC Hot Gas Filter Operating Experience:
July 1993 - April 1994**

CONTRACT INFORMATION

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Period of Performance August 2, 1989 to June 30, 1995

Schedule and Milestones

Program Schedule

	FY1990				FY1991				FY1992				FY1993				FY1994				FY1995			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Design Specification/ APF Procurement																								
Detailed Design																								
Test Plan																								
Hardware Procurement																								
Testing																								
Data Analysis																								

OBJECTIVES

The objective of this program is to evaluate the design and obtain operating experience for up to two Advanced Particle Filter (APF) systems through long-term testing on a slipstream at Ohio Power Company's Tidd Pressurized Fluidized Bed Combustion (PFBC) Demonstration Plant. Performance and reliability of commercial-scale filter modules will be monitored to aid in an assessment of the readiness and economic viability of this technology for commercial PFBC applications.

design to install a slipstream on the PFBC exhaust gases between the fluidized bed and the gas turbine to test an APF system. In November 1988, AEP submitted a proposal to the DOE for the HGCU Program, and in August 1989, a cooperative agreement was signed. In July 1990, AEP awarded a contract to Westinghouse Science and Technology Center to provide a candle-based APF. Installation of the slipstream began in December 1991, and the filter was commissioned in October 1992. Since then, over 3,000 hours of operating time have been logged on the filter.

BACKGROUND INFORMATION

The 70 MWe Tidd PFBC Demonstration Plant in Brilliant, Ohio was completed in late 1990, and is currently in a four-year test program as part of the Department of Energy's (DOE) Clean Coal Technology Program. Provisions were included as part of the original

Figure 1. HGCU System Schematic

PROJECT DESCRIPTION

System Design

In the original design, the Tidd PFBC Demonstration Plant utilized seven strings of primary and secondary cyclones to remove 98% of the particulate matter from the gases between the fluidized bed and the gas turbine. The HGCU slipstream replaces one of the seven secondary cyclones by taking the discharge gas of one of the primary cyclones to outside of the combustor vessel and into the APF. After passing through the APF the gas flows through a backup cyclone, and then returns to the combustor vessel, where the slipstream flow rejoins the combustor gas at the discharge of the other six cyclone strings.

Figure 1 provides a simplified schematic of the APF system, and Figure 2 shows an isometric view of the system.

At maximum load conditions, gas at approximately 150 psig, 1550F flows into the filter at 7600 acfm with a dust loading of approximately 600 ppmw. (In January, 1994, the dust loading to the filter was increased from approximately 600 ppmw to 3400 ppmw by detuning the primary cyclone upstream of the APF.) Ash collected in the APF is discharged to a screw cooler and into lockhoppers which feed a vacuum pneumatic ash transport system. A backup cyclone downstream of the filter is installed to clean the gas in case of a filter malfunction, and to balance the pressure drop of the slipstream with the other six cyclone strings.

Table I provides the design basis of the APF system.

Table I
APF Design Basis

Maximum Temperature	1670F
Operating Temperature	1550F
Operating Pressure	164 psia
Gas Flow Rate	100,700 lb/hr
Inlet Dust Loading	500 - 5,000 ppmw
Outlet Dust Loading	<15 ppm
Average Particle Size	1.5 microns
Temperature Drop	5F
Pressure Drop	3 psi
Face Velocity	7.1 ft/min

Figure 2. Isometric View of HGCU System

Filter Vessel

The filter vessel is 10 ft. in diameter and 44 ft. long. It is internally insulated with alumina-silica ceramic insulation, with an internal 316 stainless steel liner to protect the insulation from erosion. The hot gas enters the side of the vessel radially, flows through the candle elements, through the tubesheet, and exits from the top of the vessel head. The exterior of the APF vessel is not insulated, and is coated with temperature sensitive paint to indicate hot spots.

Filter Internals

The filter, shown in Figure 3, contains 384 candle filter elements, arranged in three clusters, spaced 120 degrees apart. Each cluster holds three plenums, each arranged vertically, with 38 candles in each of the upper and middle plenums, and 52 candles in each of the lower plenums. The candles are attached to the tubesheets in each plenum by bolted collars and high temperature gaskets.

The candles are Schumacher Dia-Schumalith F40 candles consisting of a clay-bonded sintered silicon carbide support matrix that is coated by an aluminosilicate fibrous membrane. Each candle is 2.36 in. OD and 4.92 ft. long.

The 2-in. thick tubesheet is made of RA-333 alloy, and is supported from an inverted "V" expansion cone.

Backpulse System

The backpulse system receives high pressure backpulse air from a reciprocating compressor rated at 282 scfm and 1500 psig. The air discharges from the compressor to an air dryer, and to a primary air accumulator. The air is then directed to a backpulse skid installed near

Figure 3. APF Candle Arrangement

the APF, which is comprised of secondary accumulators and the backpulse valves. The backpulse valves are fast acting (200 to 700 msec stroke time) 2-inch pilot-operated Atkomatic solenoid valves. There are three strings of backpulse valves, with redundant valves on each string.

RESULTS

The Tidd Hot Gas Filter was commissioned on coal fire on October 28, 1992. Table II presents operating statistics through April, 1994. There have been three distinct test periods since initial operation, as summarized in Table II. The results of Test Period I have been

documented in Reference 1, and will not be discussed in this paper. The results of Test Periods II and III are discussed below and summarized in Table III.

Table II
Tidd HGCU Test Periods

Test Period	I	II	III
Date	10/92- 12/92	6/93- 9/93	1/94- 4/94
No. of Runs	4	7	7
Test Period Total Hours	464	1295	1279
Longest Run, Hours	286	597	444

Test Period II: 6/93 - 9/93

Test Runs 5 and 6 - 6/30 to 7/5/93

The unit was operated for 60 hours on coal fire during Run 5, and 17 hours during Run 6. While burning Pittsburgh No. 8 coal and Plum Run Greenfield dolomite, the unit achieved a maximum load during Run 5 of 53 MW and 116-inch bed level resulting in an APF gas temperature of approximately 1400F. The APF differential pressures (DPs) remained stable during these runs and reached a maximum of 90 inches at 1400F gas temperature. (NOTE: All DP's are expressed in inches of water.)

Test Run 7 - 7/18 to 8/5/93

The unit was operated for 426 hours on coal fire burning Pittsburgh No. 8 coal and Plum Run Greenfield dolomite. PFBC performance tests were conducted at 95-inch and 80-inch bed

levels and at 85%, 90%, and 95% sulfur retention. Due to problems with gas turbine vibration, the maximum unit load obtained was 46 MW at 110-inch bed level resulting in 1350F APF gas temperature.

Most of the operating time during this run was at 80-inch bed level and 1150F gas temperature. During these operating conditions, the APF DPs were stable at approximately 60-inches trigger and 50-inches baseline. The maximum DP obtained during this run was 105 inches during an excursion at 100-inch bed level and 1250F gas temperature.

The unit was shut down on 8/5 due to ash buildup in the APF hopper that was approaching levels up to the candles. Following shutdown, an inspection revealed three to four inches of ash buildup in areas on the hopper walls. Additionally, a large amount of ash fell off the hopper walls during unit shutdown. Prior to this test series, a pneumatic vibrator was installed in the APF vessel manway and linked to the hopper liner in an effort to keep ash from accumulating on the wall of the hopper. The vibrator, however, did not prove to be effective. Therefore, it was replaced with a larger single impactor-type pneumatic vibrator following this run.

Post-test inspection revealed a small amount of ash buildup on the candles; however, there was no splotching. In general, the candles appeared to be in good shape.

Test Runs 8 and 9 - 8/9 to 8/14/93

During most of the run the unit was operated at 115-inch bed level resulting in 1400 and 1450F APF gas temperatures. The APF DPs were unstable at this load. The trigger DP increased from 90 inches on the afternoon of 8/11 to 150 inches on the morning of 8/14. On 8/12, the backpulse pressure was increased

Table III
Summary of HGCU Operation - Test Periods II and III

	Operating Hours	Cumulative Hours	Operating Temp.	Pressure Drop	Inspection Observations
Test Period II					
Run 5 & 6	75	541	<1400°F	Stable	● No filter issues
Run 7	426	967	1150°-1350°F	Stable	● No filter issues
Run 8 & 9	80	1047	1450°F	Increasing Δp , Pulse pressure increased from 800 to 1000 to 1200 psig	● Patchy cleaning ● No ash bridging
Run 10	116	1163	1450°F	Slowly increasing Δp , pulse pressure at 1200 psig	● Patchy cleaning ● No ash bridging
Run 11	597	1759	1450°F 1200°F	Increasing Δp $\Delta p = 240$ in. wg Stable Δp	● Outlet dust first detected (after 300 hours) ● Significant ash bridging, failed candles
Test Period III					
Run 12	19	1778	1300°-1400°F	Stable	—
Run 13	333	2111	1300°-1400°F	Stable	● Uniform residual ash cake ● No failures ● Ash accumulated on dust sheds
Run 14	23	2134	1200°-1300°F	Stable	—
Run 15	151	2285	1250°-1370°F	Stable	—
Run 16	145	2430	1350°-1400°F	Stable	—
Run 17	164	2594	1300°-1425°F	Gas flow rate decreased during run	● Ash cake about 1/4" thick ● No failures ● Ash accumulation on sheds
Run 18	444	3038	1350°-1450°F	Baseline Δp increased ~ 20 in. wg	● 28 broken candles ● Inner rows of top and middle plenums heavily bridged

from 800 to 1000 psig. On 8/13, the tank pressure was increased to 1200 psig and the backpulsing time interval was increased from 30 minutes to 60 minutes. Prior to the unit trip on 8/14, the APF DP reached 150 inches trigger and 115 inches baseline.

Test Run 10 - 8/19 to 8/24/93

The unit was operated for 116 hours burning Pittsburgh No. 8 coal. The unit was started up using Plum Run Greenfield dolomite, and on 8/24 sorbent feed was switched to Delaware limestone. The unit was shut down 13 hours later due to unstable bed and evaporator conditions experienced while burning limestone. Sulfur retention was maintained at 95% from start-up through the morning of 8/22 and then at 90% for the remainder of the run. The unit was operated at 115-inch bed level and 1450F APF gas temperature for most of the run. The maximum unit load was 52 MW at the conditions stated above.

During operation at 115-inch bed level and 1450F gas temperature, the APF DPs were somewhat unstable; however, not as severe as in Run 9. The trigger DP increased from 95 inches on 8/21 to 115-inches on 8/24, while backpulsing at 1200 psig. When sorbent feed was switched over to Delaware limestone, the baseline DP increased from 90 to 100 inches while the trigger DP remained fairly constant.

Post-test inspection revealed splotchy areas of ash buildup on the candles. The candles were backpulsed during unit shutdown with little success in removing the ash buildup. The APF hopper walls also had areas of ash buildup.

Test Run 11 - 8/29 to 9/23/93

The unit was operated for 597 hours burning Pittsburgh No. 8 coal. The maximum unit load

achieved during this run was 55 MW at 125-inch bed level, resulting in an APF gas temperature of 1500F. During start up while increasing load to 115-inch bed level and 1450F gas temperature, sorbent fines (Plum Run Greenfield dolomite, 100% less than 75 microns) were added to the coal water paste while reducing the pneumatic sorbent feed rate by approximately 50%. During this time period the APF DPs started to increase at a rate greater than had been experienced during previous load increases. While at temperatures over 1400F, the APF trigger DP increased from 100 to 168 inches over a period of two days. The baseline DP increased from 84 to 154 inches during this same time period. It is unknown whether this increase in DPs was due to the sorbent fines or whether it was a more aggressive deterioration of APF performance (due to some other phenomenon) than what had been experienced previously at temperatures above 1400F.

On 9/9, the APF trigger DP reached 250 inches, at which time it was decided to reduce unit load to 50-inch bed level, 1000F gas temperature to backpulse the APF. The APF DP was reduced to 145 inches by load reduction and dropped to 36 inches after minimum load backpulsing. However after unit load was brought back to 115-inch bed level, 1450F gas temperature, the APF trigger DP reached a level of 250 inches in less than two days. Load was reduced to 80-inch bed level, 1200F gas temperature to maintain DPs within acceptable limits.

On 9/12 and again on 9/13, indications of candle breaks were noticed by a sudden decrease in APF DP (by approximately 10 inches) and a sudden increase in individual plenum gas flow which occurred simultaneously while backpulsing. Later on 9/13, fragments of broken candles were recovered from the ash removal system. The total fragments recovered could not positively account for more than one

candle. Figure 4 shows a graph of filter pressure drop and temperature for the entire run. The unit was removed from service on 9/23 due to a leak in the sorbent transport pipe caused by erosion.

Post-Test Inspection and Modifications

The APF internals were inspected through instrument nozzles and the manway nozzle on 9/27 and 9/28. During this inspection approximately 24 candles were observed to be broken. The ash hopper was filled with ash and broken candles to a level approximately 6 to 12 inches above the manway nozzle.

On 9/30, the APF internals were removed from the APF. Upon inspection, 62 candles were found to be broken. Approximately three candles were broken during removal from the APF vessel. The following table shows a summary of the location of the broken candles.

Location of Broken Candles September 1993

	Plenum A	Plenum B	Plenum C
Top	3	1	2
Middle	6	24	5
Bottom	0	1	20

Very heavy ash bridging was apparent between candles and between candles and support pipes. The deposits were very hard and difficult to break into smaller pieces. Many candles were also found to be bowed. During subsequent cleaning of the ash deposits from the candles, approximately 40 more candles broke.

Two surveillance candles were recovered by Westinghouse and tested for remaining hot strength. One candle from the original set, which had been exposed to operating conditions for 1,759 hours, exhibited a 37 percent loss of

1. Reduced load.
2. Reduced load.
3. Candle breaks.
4. Reduced load.
5. Spoiling air on.
6. Candle breaks.

Figure 4. Filter DP and Temperature - Test Run 11

its original strength. The second candle, which had been installed in December 1992 and had experienced 1,295 hours of operation, had lost 51 percent of its strength.

All filter candles were replaced with new silicon carbide candles between Test Series II and III, except for nine surveillance candles which were reused.

The backpulse solenoid valves exhibited random failures to actuate during these tests. In all cases, the backup valve functioned properly. Following Test Period II, the backpulse solenoid valves were inspected and found to be galled on both the piston and cylinder walls. The valve pistons were Stellite coated and the valve body bores were nickel-boron plated to improve resistance to galling. Following these modifications, the valves successfully underwent accelerated cycle testing to verify the design. Operation of the valves during Test Period III was much improved, and subsequent inspections revealed no galling.

At the end of Test Period II, one backpulse tube was cut up and examined for degradation. Microcracking was evident on the inside surface of the tube, with cracks as deep as 0.020". Based on this observation it was decided to replace the Incoloy 800HT material with Haynes 230 alloy, which has better resistance to thermal fatigue. The new backpulse tubes were fabricated and installed prior to the start of Test Period III.

Between Test Series II and III, nine additional air purge nozzles were installed on the APF hopper to facilitate the removal of ash accumulation in the hopper. The hopper vibrator was moved from inside the APF nozzle to outside the nozzle because it proved to be unreliable inside the nozzle. It was mechanically linked to the hopper liner.

In an effort to improve the filter

performance, it was decided to install a system to detune the primary cyclone upstream of the filter. It was believed that the resulting coarser ash would be easier to remove from the filter candles and less likely to accumulate on the hopper walls. An air line was connected to the dip leg of the cyclone and a valve was installed external to the combustor to allow the detuning air to be controlled. Air injected into the dip leg created an upward velocity and thereby detuned the cyclone. All testing during Test Period III was conducted with the cyclone detuned.

It was noted in previous runs that the filter DP sometimes became unstable at gas temperatures over 1400F. To prevent limiting the load on the unit because of the 1400F limit, a tempering air line was installed upstream of the filter which allowed 580F process air at a slightly higher pressure to be mixed with the gas and thereby reduce the gas temperature by as much as 150F.

Test Period III: 1/94 - 4/94

Test Run 12 - 1/10 to 1/11/94

This test run was terminated after 19 hours of coal fire when several primary cyclones became plugged. Due to the brevity of this run and lack of steady state operation near design conditions, it will not be discussed further.

Test Run 13 - 1/15 to 1/29/94

The unit was operated for 333 hours on coal fire burning Pittsburgh No. 8 coal and Plum Run Greenfield dolomite. The primary objective of this run was to assess the performance of the APF while operating with the primary cyclone ahead of the filter detuned to produce a coarser ash and higher ash

loading. The tempering air system was commissioned during this run and functioned without any problems.

During the run ash sampling was performed upstream and downstream of the APF using specially designed sampling probes. The results showed that by detuning the primary cyclone, the ash loading to the filter increased from a design value of 600 ppmw to about 3400 ppmw, and the mean particle size of the ash increased from about 3 to 7 microns. The higher ash concentration resulted in significantly higher ash loading. Despite the higher ash loading, the filter performed very well.

Figure 5 shows a graph of filter pressure drop and temperature for Run 13. The unit load was reduced at about 200 and 250 hours into the run due to bed sintering problems, which accounts for the dips in temperature and DP during these periods. During the remaining periods of this run, the filter pressure drop

remained stable and exhibited the usual trend of following gas temperature. During the last 50 to 75 hours of the run, the unit bed height was increased to the maximum (142 inches), and the filter DP increased somewhat due to higher gas flow and dust loading.

Following shutdown of the unit, the filter was inspected via nine 3-in. nozzles on the side of the vessel. In general the candles looked in good condition with very little residual ash accumulation. However, some ash bridging was seen between the bottoms of the inner rows of candles and the dust sheds on the plenum support pipes.

Test Run 14 - 2/17 to 2/18/94

This test run was terminated after 23 hours of coal fire when a 1" nipple on the HGCU piping developed a leak that could not be repaired in service.

Figure 5. Filter DP and Temperature - Test Run 13

Test Run 15 - 2/19 to 2/25/94

This run was a hot restart of the previous run. The APF performed without any major problems during this run. Some minor problems, however, arose. Shortly after start-up, the APF dome exhibited elevated temperatures (up to 730F) near the gas outlet nozzle. The gas temperature was held to the 1250F range in order to keep the hot areas below 750F. On 2/21 an on-line repair was successfully made which reduced the hot areas to below 300F in some areas and to below 400F in others. The repair involved drilling and tapping three 1/4" holes in the outlet nozzle near the head and pumping in 45 gallons of pumpable insulation. Following this repair, the unit was brought up to full bed height (142 inches). Tempering air was again used to limit the gas temperature in the APF to 1400F. Figure 6 shows a graph of APF DP and temperature versus time for this run. The unit load was reduced about 110 hours into the run when a coal paste pump stopped working.

After the bed again stabilized, the unit was returned to full load. The HGCU system functioned without further problems from this point until the unit tripped due to loss of the sorbent booster compressor.

Test Run 16 - 3/3 to 3/9/94

Most of this test run was conducted at 142 and 150-inch bed levels. As in the previous run, tempering air was used to limit the filter gas temperature to 1400F. This run was the smoothest so far the HGCU system. The system operated for over 145 hours without any major problems. Figure 7 shows a plot of APF DP and temperature during Run 16. Figure 8 shows DP and flowrate. The APF DP exhibited a gradual decline throughout this run. The reason for this is unknown. The test conditions throughout Run 16 were the most steady of all the runs. Therefore, data from this run should be considered a good baseline reference for APF operation at 1400F. This run was termin-

1. Reduced load.

Figure 6. Filter DP and Temperature - Test Run 15

Figure 7. Filter DP and Temperature - Test Run 16

Figure 8. Filter DP and Flow - Test Run 16

ated when the unit tripped due to the loss of two coal paste pumps.

Test Run 17 - 3/16 to 3/23/94

This was another relatively uneventful run on the HGCU system. The unit operated for approximately 164 hours on coal fire. Most of the run was conducted at 128-inch bed level, with portions at 142-inch and 115-inch. Due to bed sintering problems, the bed level could not be maintained at 142 inches. The tempering air was turned off during this run which allowed the APF to operate up to 1450F. The filter pressure differential was relatively stable throughout the run as shown in Figures 9 and 10. However, the gas flowrate through the filter decreased throughout the run. During this run additional insulation was pumped into the APF head to lower the surface temperature in one area from 550F to 400F. The unit tripped due to a low oil pressure indication on the gas turbine.

The APF internals were inspected through the nine instrument nozzles following Test Run 17. No broken candles were observed. The residual ash layer on the candles was somewhat thicker than seen following Test Run 13 and appeared to be about 1/8" to 1/4" thick. The ash coating was uniform from candle to candle but also very rough looking on all the candles. The ash bridging previously seen between the dust sheds and the inner rows of candles was still evident, but not obviously worse than before. The amount of ash accumulation on the dust sheds varied considerably (1/2" to 4") among the six dust sheds. No candle-to-candle bridging was seen.

Test Run 18 - 3/31 to 4/18/94

This was the longest run of this test period with almost 444 hours of coal fire. The bed

height during most of the run was 115 inches and the APF temperature was generally in the 1350 to 1400F range. The temperature was approximately 1450F for about 30 hours of the run. Due to a corroded instrument tube, flowrate data were not obtained during this run. Hazardous air pollutant sampling was conducted during this run. No major problems arose with the APF during this test. The baseline pressure differential increased during this run from about 70 to 90 inches as shown in Figure 11. This was the first run of this test series in which the DP increased noticeably from the beginning to the end of the run.

As part of Hazardous Air Pollutant testing, SO₂ data were obtained upstream and downstream of the APF. Preliminary results indicated that the SO₂ level in the gas was reduced approximately 45% by the APF. Post-test analysis of ash samples retrieved from the APF and precipitator hoppers confirmed this observation. The percent sulfation (calculated as moles of SO₃/moles of CaO) of the APF hopper ash was 78.6% as compared to 50.0% for ash that did not pass through to APF sampled from the precipitator hopper. Additional data will be obtained in future tests to confirm these results.

Post-Test Inspection and Modifications

The APF internals were inspected via the instrument ports after this run. The filter candles had a thin layer (about 1/8") of residual ash, however broken candles were observed during this inspection. The filter internals were removed from the APF vessel on 5/5/94 and a more detailed inspection was performed. A total of 28 broken candles were found at the following locations:

Figure 9. Filter DP and Temperature - Test Run 17

Figure 10. Filter DP and Flow - Test Run 17

Location of Broken Candles May 1994

	Plenum A	Plenum B	Plenum C
Top	7	7	2
Middle	0	2	8
Bottom	0	2	0

The two breaks in the bottom plenum are believed to have occurred during removal of the filter internals from the filter housing. Very heavy ash bridging was observed between the inner rows of candles and the support pipe on the top and middle plenums. The ash build-up extended over the entire length of the inner candles. In some cases the ash bridging extended into the outer rows of candles. Many of the inner candles were bowed outward and in some cases almost contacted the candles in the outer row. All of the candle breaks except one appeared to be fresh breaks judging from

the clean fracture surfaces. All of the breaks occurred at the top of the candle just below the candle holder. The breaks appeared to result from bending forces from ash bridging from the inner candles to the outer candles. Only one break was in an inner row; the remainder were in outer rows.

The outlet side of the filter internals were very clean with virtually no ash deposits. This is further indication that the failures occurred during or after plant shutdown, and that the filter was not leaking ash to the clean side during operation.

FUTURE WORK

At the end of April the system was out of service and plans were being formulated for modifications and future testing. It is planned to remove the inner rows of candles from the

Figure 11. Filter DP and Temperature - Test Run 18

top and middle plenums since the ash bridging phenomenon appeared to begin with ash building up on the dust sheds and bridging across to the bottoms of the inner candles. It is hoped that the removal of the inner rows of candles will eliminate this problem. In addition, plans are being implemented to modify the primary cyclone ahead of the filter so it can be rendered totally inactive. This will increase the ash loading and mean particle size to the filter and thereby improve the flowability of the ash. During this shutdown some alternate filter candle materials will be installed to expose them to the Tidd PFBC service conditions.

Assuming that these modifications are successful in overcoming the ash bridging problem, the system will be operated until the fall of 1994 with the current silicon carbide candles and selected alternate candles. The condition of the alternate materials will be assessed when the filter is re-opened in the fall of 1994. At that time, a decision will be made as to what filter materials will be installed for the final phase of testing which will run until February, 1995.

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