Test Results from the Department of Energy's Pressurized Fluidized Bed Combustion Hot Gas Cleanup Program

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Presented here is a summary of operations and conclusions from the last two test campaigns of the Department of Energy's Pressurized Fluidized Bed Combustion Hot Gas Cleanup Program which was implemented by the American Electric Power Service Corporation. In these tests, the Westinghouse Advanced Particle Filter (APF) operated on a one-seventh flow from the Tidd 70-MWe Pressurized Fluidized Bed Combustor. During these tests, the filter operated as predicted with extremely high particulate removal. During the combined test periods, more than 2,800 hours of operation were accumulated -- two operational periods lasted more than 650 hours. The completion of this program brings the total coal fired operating time of the APF to 5,854 hours.

Introduction

In August 1989, a cooperative agreement was signed between Ohio Power Company, through its agent the American Electric Power Service Corporation, and the United States Department of Energy to assess the readiness and economic viability of high-temperature and high-pressure particulate filter systems for pressurized fluidized bed combustion (PFBC) applications. The major objective of the project is to evaluate integrated engineering designs of selected particle control technologies by using a slip stream test (10 MWe) at the Tidd 70-MWe PFBC facility. Through a competitive selection process, the Westinghouse Science & Technology Center's Advanced Particle Filter was selected for the demonstration test.

In the implementation of this program many issues were addressed including filter system components, filter element degradation, and filter system operation and integration. Many of the results from this work can be found elsewhere in the literature [1,2,3]. Presented below is a brief summary of the last two test campaigns from the Tidd slip stream testing, and the major conclusions from the PFBC Hot Gas Cleanup Program.
Prior to the start of test campaign IV, three system modifications were implemented. One was the removal of the inner ring of candle filters on all top and middle plenums of the APF. The filter removal reduced the number of filter elements from 384 to 288 and, consequently, increased the operational face velocity by 25 percent. The second modification was to install a system for spoiling (reduce in performance) the cyclone upstream of the APF. Both of these modifications were done to avoid filter ash bridging problems encountered in earlier tests. The third modification was the inclusion of several types of experimental candle filter elements.

**Test Campaign IV: 7/94 - 10/94**

The first two tests 19 & 20 (7/16/94) together totaled only four hours and, therefore will not be discussed. Test 21 (7/20-27/94) totaled 161 hours, and was terminated to repair a vibration problem on the gas turbine. Because of the turbine limitation, the APF temperature was in the 607 to 621 °C range during most of this run. The APF differential pressure remained stable during the run at approximately 13.6 kPa. Test 22 (7/28 - 8/25/94) was a hot restart from the previous run, and was the longest run to date for the APF system at just less than 680 hours. During this test, the APF operated between 650 to 760 °C, additionally, various sorbents were tested. The APF pressure drop (DP) exhibited periods of instability during this run.

At the end of test 22, the APF had logged 844 hours of operation since it was reconfigured with 288 candles. The objective of this test series was to determine if removal of the inner rows of candles from the upper and middle plenums would eliminate ash from accumulating on the ash sheds and bridging over to the candles. An inspection on August 29, 1994 revealed that ash bridging, while less than before, had still occurred. The APF hopper was clean two days following shutdown, but when inspected again four days following shutdown, ash was found in the hopper. During the inspection with a boroscope, 14 broken filter candles were seen, and candle pieces were later removed from the hopper. Nine candle bottoms were recovered in the hopper. A possible explanation for the candle breakage would be that ash, bridged between the ash sheds and candles, expanded slightly during cooling and absorbed moisture from the air, thereby inducing bending moments on the candles which all failed near the top of the filter holding fixture. Another possible explanation is that the metal support pipe contracted more than the ceramic candles upon cooling, which induced bending stresses in the candles due to ash wedged between the candle bottoms and sloping dust shed surfaces. It was decided to continue this test series with 14 broken candles rather than declare the system out of service at this time in order to replace them. It was planned to replace all of the candles in the fall of 1994.

Test 23 (9/3-10/94) was a 171-hour run. During the last 90 hours of test, the primary cyclone was spoiled by injecting air into the ash pickup nozzle to reduce the ash transport ability and force the ash to build up in the dip leg of the cyclone. In order to even out the ash discharge from the APF, the back
pulsing sequence was changed to produce uniform cleaning. Each plenum was back pulsed every 15 minutes with back pulses occurring every 1.67 minutes. During this period the APF temperature was in the 704 to 760 °C range and the DP was stable. Ash removal during this run was difficult since the lock hopper system could not keep up with the approximately 0.21 kg/s of ash flow. A new emergency ash removal line was successfully used to overcome this problem.

Following this run a post-test boroscope inspection was conducted (9/14/94) on the APF. This inspection revealed most of the ash bridges seen in the previous inspection had disappeared, and the few that remained appeared smaller. This indicated that the coarser ash was cleaning the ash accumulation from the ash sheds. The liner and hopper also were clean of ash deposits. No additional broken candles were observed.

During test 24, (9/22/94 - 10/21/94), it was decided to operate the unit with the primary cyclone only partially spoiled for the first three weeks of this scheduled four-week run. This was due to erosion problems in the ash removal line of the back-up cyclone. The cyclone was spoiled during the last four days of the run. During this test of 691 hours, the DP, increased significantly during the first 300 hours (from 20 kPa to 38 kPa), increased gradually over the next 300 hours (from 38 kPa to 42 kPa), and increased dramatically when the cyclone was spoiled due to the increased ash loading (up to 49 kPa).

On 10/27/94 a post-test inspection was conducted where the APF internals were removed from the vessel for inspection and candle replacement. Thirty candles were observed to be broken.

Ten of the 30 breaks had clean fracture surfaces indicating the breaks occurred after shutdown or during removal from the vessel. Heavy ash bridging was apparent near the bottoms of candles in the top and middle plenums of cluster B, while light to moderate ash bridging was seen in the top plenum of cluster C, bottom plenum of cluster A, and the bottom plenum of cluster B. It was evident that the ash accumulation that occurred during the first 600 hours of this run was not removed during the last 90 hours of operation with the cyclone spoiled.

Two of the nine back pulse tubes were found to have longitudinal cracks through the wall about 305 to 406 mm long. The cracks occurred only on two of the bottom plenum tubes, which were back pulsed at a higher pressure (89.7 bar) than the upper and middle plenums (69.0 bar). The cracks were believed to be caused by thermal fatigue. All nine tubes were replaced with Haynes Alloy 230.

The primary cyclone upstream of the APF was modified between Test Campaigns IV and V to force all the gas and ash to flow through it and not collect any ash. This was done in hopes of demonstrating that the APF would operate at design temperature (840 °C) without ash bridging and without the formation of hard ash cake deposits on the filter candles, which had caused the filter DP to become unstable in prior tests runs.
Test Campaign Period V: 1/95-3/95

Tests 25, 26, and 27 (1/13-21/95) had operational durations of 4.4, 16.8, and 7.1 hours, respectively. In each case, the unit was shut down due to a problem not related to the filter system. Due to the brevity of these runs, they will not be discussed.

Test 28 (1/27/95 - 2/2/95) lasted 145 hours and was terminated when a blind flange temperature exceeded 732 °C because of the loss of insulation. It was found that the anchor pins which held a stainless steel cover plate over the insulation boards corroded which allowed the plate to fall away from the insulation. The gas flow entrained the insulation and carried it through the gas turbine. Portions of four anchor pins were also carried into the turbine, and one of them passed through the turbine causing minor blade damage. (The blind flange was downstream of the backup cyclone.) During the early part of this run, problems with ball valves and pressure regulators on the back pulse skid interrupted filter cleaning for some periods, which resulted in abnormally high DP (on the order of 44 kPa). During the last half of the run, the filter DP was stable with the gas temperature at 815 °C. During the run, approximately 41 liters of Fiberfrax insulation were pumped into the APF head to control three hot spots.

Following test 28, the APF was inspected using a boroscope passed through three instrument nozzles on the side of the filter vessel. The filter internals were found to be clean with no ash bridging seen between the candles and the ash sheds. One very minor ash accumulation was seen between two candles in a bottom plenum, but overall, the filter looked cleaner than it had since the inspection following test 1. The bottom of the APF hopper was also without significant ash deposits. Very little (less than 1/8") ash coating was observed on the candles. It was obvious that the coarser ash resulting from bypassing the primary cyclone was much easier to remove from the candles and did not tend to stick to the sides of the hopper, thereby making ash removal a non-issue.

Tests 29 and 30 (2/9-10/95) had operational durations of 14.7 and 14.4 hours respectively. Test 29 was terminated due to a failure unrelated to the APF, and test 30 was terminated to repair a gasket leak at the inlet of the ash surge hopper. Due to the brevity of these tests, they will not be discussed.

Test 31 (2/11-12/95) accumulated 32 hours of operation and was terminated when the alternate ash line became plugged and the APF hopper began filling with ash. During the run, candle fragments were found in the ash line from the lock hopper. Additional fragments were found upon shutdown in the alternate ash line while it was being cleaned. It is believed that a candle fragment became lodged in the orifice of the alternate ash line causing it to plug. The candle filter was one of the experimental elements.

Test 32 (2/12-16/95) was a hot restart of the previous run. This test duration lasted 73 hours, and was terminated due to plugged coal paste pumps. Early in the run, the APF head
exhibited additional hot spots, and another 190 liters of Fiberfrax insulation were pumped in to correct the problem. Once the gas temperature reached 788 to 815 °C, the APF DP remained fairly stable at 35 kPa.

Following shutdown, another candle fragment was found in the lock hopper isolation valve. This fragment was the same material as the earlier fragments, and is believed to be from the same broken candle. In order to prevent the alternate ash line from becoming plugged by a candle fragment, a perforated plate was added at the inlet of the ash line between test 32 and 33.

Test 33 (2/18/95 - 3/8/95) was one of the longest runs of the program at 427 hours. It was also the first run which the filter operated at or above 845 °C for significant time periods. The Tidd PFBC unit reached its maximum output during this run, and the APF operated above 845 °C during three separate time periods (totaling 60 hours). The APF remained relatively stable during this run, but there was a noticeable increase in the DP following the last test at 845 °C. The plant did not operate at full load for longer than about 20 hours at a time, so it is not known if the filter DP would have become unstable at 845 °C for longer time periods. During this run, the APF head had to be pumped again with 76 additional liters of insulation to control hot spots. On February 24, the ash line from the Backup Cyclone became plugged, and for the remaining 12 days of the run no ash could be removed from the cyclone. The run ended when the coal paste pumps plugged. Following shutdown, the backup cyclone was opened and found to be nearly full of ash.

Test 34 (3/14 - 30/95) was the final test run of the APF system as the Tidd Plant was shut down permanently afterward. The run time exceeded 375 hours; which was the second longest of the test campaign. Two days after the start of this test run, APF candle fragments were removed from the lock hopper system. The fragments were examined, and it was determined that they came from the experimental candle filters. The candle breaks apparently occurred during the first two days of this run. No other candle fragments were found for the remaining 13 days of the run. Most of this run was conducted at 2.28 m and 2.92 m PFBC bed level, and as a result, the APF temperatures ranged from 677 to 760 °C during most of the run. The DP was constant at a given temperature, but showed a slight increase during the last two days of the run.

On 4/26/95, the internals of the APF were inspected with a boroscope. The internals were clean with no ash bridges observed. Many of the experimental filter candles appeared to be missing or were partially broken off. The remaining candles appeared in good condition. These observations were confirmed when the filter vessel internals were removed for inspection.

CONCLUSION

The Tidd PFBC Hot Gas Clean Up System has logged more than 5,800 hours of operation since initial start-up in October, 1992. Major conclusion from this test program are listed below.
1. The basic design of the APF is structurally adequate. The hot tube sheet, candle holders, cluster design and plenum configuration are an appropriate design.

2. The majority, if not all, of the broken candle elements can be attributed to ash bridging in the APF. The ash bridging appears to be strongly influenced by the size and temperature of the ash entering the filter. Fine ash (1 to 3 microns) discharged from a well-tuned cyclone builds an ash cake on the filter candles that is extremely difficult to remove at operating temperatures over 760 °C. Ash from a partially de-tuned cyclone (about 7 microns) is more easily removed than the smaller ash, but still difficult to remove at operating temperatures over 787 °C. On the other hand, ash discharged from a completely spoiled cyclone (about 27 microns mean particle size) is easily removed and does not tend to bridge. This ash is also much easier to handle in the ash removal system.

3. Clay bonded silicon carbide filter candles exhibit a significant (50 percent or more) decrease in strength after exposure to the PFBC operating conditions. The decrease in strength appears to level off after about 1800 hours of exposure.

4. Based on gas stream sampling the APF reduces the SO₂ concentration in the gas passing through it by approximately 40 percent [4]. This is believed to result from the gas reacting with ash cake on the filter candles.

5. Based on inlet and outlet gas stream sampling across the filter the APF is capable of removing particles at an efficiency of 99.993 percent [4].

REFERENCES


3. Dennis, R. A., Lipperet, T. E., Mudd, M. J. et al., Initial Test Results from the Department of Energy’s Pressurized Fluidized Bed Combustion Hot Gas Cleanup Program, Tenth Particulate Control Symposium and Fifth International Conference on Electrostatic Precipitation, April 5-8, 1993, Washington, DC.