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SECOND YEAR OF OPERATION OF THE TIDD PFBC DEMONSTRATION PLANT

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ABSTRACT

The Tidd PFBC Demonstration Plant is the first utility-scale PFBC demonstration project in the United States. Its objective is to demonstrate that the pressurized fluidized bed combustion (PFBC) combined-cycle technology is a cost effective, reliable, and environmentally acceptable alternative to conventional coal fired electric power generation using flue gas desulfurization.

The project will demonstrate PFBC technology on a large scale for use in commercial combined-cycle electric generating plants. The program will demonstrate gas turbine survivability and controllability; process performance in removing oxides of sulfur and minimizing the formation of oxides of nitrogen; equipment and system performance and reliability.

This paper reviews problems encountered during the first year of unit operation, the modifications made during an outage in the Fall of 1991 to correct these problems, and the post outage operating experiences through July 1992.

INTRODUCTION

Tidd, an electric generating station in Brilliant, Ohio, is the first utility scale pressurized fluidized bed combustor to operate in combined-cycle mode in the United States. The plant is owned and operated by Ohio Power Company and is located on the banks of the Ohio River, approximately 75 miles downstream of Pittsburgh, Pennsylvania. The project is being co-funded by Ohio Power Company, a subsidiary of American Electric Power (AEP), the U. S. Department of Energy (DOE), and the Ohio Coal Development Office (OCDO).

The Tidd project involved repowering a 45 year old power plant with PFBC components in order to demonstrate that this technology would burn coal efficiently while capturing 90% of the sulfur in the ash and emitting significantly less nitrogen oxides than conventional coal burning power plants.

The PFBC related equipment was supplied by ASEA Babcock, a partnership between ASEA Brown Boveri Carbon (ABB Carbon) and the Babcock & Wilcox Company (B&W). American Electric Power Service Corporation (AEPSC) engineered and designed the remainder of the plant. Construction and modification of the existing facility was carried on by Ohio Power Company.

Detailed design work on the project began in May 1986 and site construction work started in April 1988. Unit start-up was initiated in November 1990 immediately following completion of pre-operational system testing. The first combined cycle operation was achieved on November 29, 1990 and on February 28, 1991 the three year demonstration period began.

OPERATIONAL OVERVIEW

From November 1990 through September 1991, the unit operated on coal for a total of 818 hours with the longest continuous run being 110 hours. During this period of time, the unit experienced a number of operating difficulties. Throughout this period, modifications were continuously being made that improved unit operability. In mid September 1991, the unit was taken out of service for a 12 week outage to make major modifications to improve unit performance and further improve unit reliability. The unit was returned to service in December 1991. After some initial problems, the unit began to operate more consistently; however, run durations were still limited by operating problems. From December 15, 1991 through March 5, 1992 the unit fired coal for a total of 530 hours with the longest run being 154 hours. In mid March 1992, vibration induced cracks were discovered on the low pressure turbine blade roots. As a result, a nine week outage was taken to replace the blades as well as to install and place in service a portion of the hot gas clean-up test system. Additionally, a significant coal crusher test program was undertaken during this outage in an attempt to improve coal paste quality and crusher reliability. The unit was returned to service on May 10, 1992, but experienced a leak in an expansion joint of the newly installed hot gas clean-up piping. The hot gas clean-up piping problem was determined to be too complex for a quick resolution, therefore it was decided to blank-off the one cyclone string used by hot gas clean-up and to run the unit with just six cyclone strings.

The unit was returned to service on June 9, 1992. It ran continuously for 31 days at nearly 70% capacity factor. It was taken out of service in a controlled manner on July 10, 1992, for equipment inspections.

SYSTEM/COMPONENT OPERATING EXPERIENCE

In-Bed Combustion

Post-bed combustion in the cyclones was experienced during the first year of operation. Two types of fires occurred. The first type occurred mainly at low loads and they were centered in the dip leg region of the cyclone. These were attributed to excessive carryover of carbon at the lower bed heights and were particularly present when sorbent injection was not in-service. The other type of fire involved the entire gas stream through given cyclone strings. This type of fire was attributed to combustion of volatiles that had not burned in the bed due to oxygen depletion plume effects near the fuel nozzle outlets. Efforts were directed at achieving better distribution of the fuel into the bed, which resulted in some improvements. It was also determined that with dryer coal paste the intensity of the fires could be reduced. This was theorized to be due to the ability to achieve larger and more consistent sized agglomerates in the bed with dry paste, which in-turn slowed down the volatile release rate.

During the fall 1991 outage, additional modifications were made to the fuel injection system to achieve better distribution of the fuel. In addition, in order to preclude excessive individual cyclone string temperatures associated with volatile fires, a freeboard gas mixing system that employed steam jets was installed during the outage. The intent of this system was to achieve combustion of any escaping volatiles in the freeboard region. This would spread that heat release over the entire gas flow rather than allowing it to concentrate in one or two cyclone strings where it would result in temperatures that approached material limits and thus necessitated a trip or load reduction. In addition to these physical modifications, further efforts were expended during the outage to attempt to produce dryer coal paste that was pumpable.

During the runs that followed from December 1991 to March 1992, the above efforts produce a noticeable improvement on volatile fires, however, on going efforts to dry out the paste frequently resulted in coal injection line plugs. One new problem developed. The cyclone dip leg fires that had previously only occurred at low loads were now occurring at much higher loads in selective cyclone strings. These fires were able to be controlled through use of the freeboard steam mixing system that apparently acted to more evenly distribute the unburned carbon to the cyclone strings.

Presently with improved coal paste and the use of freeboard mixing, the unit operates with no evidence of any significant dip leg or volatile fires.

Boiler

The amount of in-bed tube surface initially installed was inadequate and resulted in achieving only 73% of design in-bed heat absorption at the original full bed height of 126 inches. During the fall 1991 outage, approximately 25% more in-bed surface was added above the existing bundle with the intent to achieve full design absorption. Due to the presence of post-bed combustion and gas turbine inlet temperature limitations, the design bed temperature used to size the surface addition was 1540°F versus the 1580°F original design value. At the new full bed height of 140 inches, the in-bed surface is presently absorbing approximately 93% of the design absorption. Investigations are underway to determine the reason for the remaining shortfall.

Economizer

The finned tube economizer has exhibited significantly heavier fouling than originally anticipated. This fouling resulted in excessively high gas side velocities. Vibration induced by these high velocities is believed to be the cause of four tube leaks that occurred during the summer of 1991. In order to combat these problems, four sootblowers and additional economizer vibration ties were installed during the fall, 1991 outage. While no additional tube leaks have been experienced since then, there was still heavy fouling in regions of the economizer that the sootblowers could not reach. Four additional sootblowers have been installed.

Sorbent Injection System

At initial start-up, this system experienced numerous operating difficulties related to valve and rotary feeder binding and wear. Through rotary feeder material and drive modifications and valve repair and replacements this system is now very reliable.

In addition to the above noted problems, the transport piping experienced severe erosion at the bends. These bends, which are essentially crosses, originally had a hardened steel lining. The crosses have been replaced with ceramic lined material which has held up well. However, the last piping segments which are stainless steel and act as the injection nozzles have experienced accelerated erosion. This problem is presently under investigation. The straight piping sections which also have a hardened steel lining have not experienced erosion.

An additional problem encountered with this system was the formation of sorbent based clinker deposits in the tube bundle above the injection nozzles and adjacent coal nozzles. The clinkers, which were formed from very fine sorbent particles with no evidence of melting, appeared for the first time in January, 1992. Since there had been no major changes to the sorbent injection system prior to the clinker formation, the cause for modifications, further efforts were expended during the outage to attempt to produce dryer coal paste that was pumpable.

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Coal Preparation/Coal Injection System

The coal preparation system was designed to crush 3/4" x 0 coal to a specific size that was suitable for both paste pumpability and combustion within the fluidized bed. For pumpability, the most critical parameter is that 20% of the crushed coal must be -325 mesh which then permits the moisture content of the paste to be lowered to the 24% to 25% range by weight. As the percent of -325 mesh fines declines below 20%, the moisture content must be increased to maintain good paste pumpability characteristics.

During the first 14 months of operation, the coal crusher was not capable of producing the proper size of coal required for good pumpability. With the coal fines fraction varying from 12% to 15% through -325 mesh, the moisture content of the paste had to be maintained in the 25% to 28% range which had negative impacts on in-bed combustion and post bed cyclone fires.

During this period, numerous changes were made to the crusher system to improve the -325 mesh fines fraction without success. Modifications included installation of larger drives, installation of grooves on the flat roller surface, and several different control modes. The latest modification was completed just prior to the gas turbine outage in March 1992 when a recycle loop was added to the crusher. This permitted 100% of the feed coal to be recycled through the crusher a second time, producing the desired amount of -325 mesh fines. The 31 continuous day run in June 1992 verified this operating mode when coal paste -325 mesh fines ranged from 18% to 22% and moisture contents were consistently maintained at 24% to 25% moisture by weight.

The other significant modification in the coal paste system was in distribution of paste within the paste storage tank which appears as an hourglass shape in plan view. With the paste being fed on the extreme left side of the tank, the moisture distribution across the tank was poor. The right side of the tank was always wetter than the left. This phenomenum carried throughout the combustion process. The three left side injection pumps and nozzles saw less water and were more prone to plug. The right side of the fluidized bed, which saw higher moisture contents, experienced more significant post bed combustion.

In May 1992, the coal preparation system was modified to deposit prepared paste into both sides of the tank. During the 31 day run, the proper size paste and good tank distribution resulted in minimal pump pluggages and more uniform post bed temperatures.

The other modification made to the coal prep/coal injection system was with regard to corrosion. The Pittsburgh #8 seam coal, when mixed with water, produced a paste with a pH of 3. This resulted in significant corrosion of the coal mixer and paste pumps from November 1990 through September 1991. During the fall 1991 outage, all carbon steel surfaces in the mixer and paste pumps were replaced with stainless steel and some minor components were coated to prevent corrosive attack. To date, these modifications have been successful.

Gas Cleaning Cyclones/Ash Removal Systems

The gas cleaning cyclones were designed to clean the ash laden gas stream from the freeboard down to an ash loading that would not result in unacceptable erosion of gas turbine blades and components. The cyclones consist of seven parallel strings of cyclones, each with two stages of cyclones, a primary and a secondary cyclone.

The ash collected in each cyclone is pneumatically transported out of the combustor vessel.

During the plant operation from December 1990 through March 1991, pluggage of the secondary cyclone ash removal system resulted in unacceptable unit availability. As such, numerous modifications were made to the secondary ash removal system to reduce the system pressure drop and thus increase transport capacity.

Originally, the seven primary and seven secondary ash lines combined into one line which was then routed to the cyclone ash silo. By March 1991, the primary and secondary systems were decoupled and the secondary ash line was routed instead to the precipitator inlet. In addition, several modifications were made to the ash lines inside of the combustor vessel to further improve transport capacity.

Starting in March 1991, in-service secondary ash transport capacity was sufficient to permit reliable operation of the secondary ash system. However, at shutdowns, ash buildup in the cyclone dip legs would not permit restart of the unit until that ash was removed from the dip leg. In order to minimize the impact of this buildup on unit operation, the dip legs on all secondary cyclones were shortened approximately 20 feet by the end of the fall 1991 outage.

After the fall 1991 outage, pluggage of the secondary ash system again impacted unit availability. In mid-January 1992 the plugs were found to be caused by excessive pressure drop in the secondary ash line external to the combustor vessel. The excessive pressure drop was eliminated and the system began to function properly. Operation during the spring of 1992 has indicated the secondary ash removal system is now marginally acceptable. Plugs still occur at start-up; however, they generally unplug as the pressure vessel pressure increases after coal fire. During the 31 day run though, one cyclone remained plugged throughout the run. This was found to be due to a restriction caused by a foreign object.

As opposed to the secondary ash removal system, the operation of the primary ash removal system has been acceptable except for a two month period in mid 1991. Starting in June 1991, pluggage of the primary ash removal system began to impact unit operation. At first, each plug could be traced to a system upset usually in the sorbent injection system. It was thought that the system upset resulted in a temporary increase in ash to the cyclones which overwhelmed the ash transport capabilities. However, in September 1991, the system was totally dismantled and inspected as part of the fall 1991 outage and the real cause was discovered. During the outage, it was found that air inleakage into the primary ash line flanged connections inside the combustor vessel significantly reduced the transport capacity of the system. Therefore, the system upsets merely overwhelmed a system that was operating at marginal capacity.

During the fall 1991 outage, all bolted flanges in the secondary and primary ash lines inside the vessel were disassembled and inspected. At that time it was found that shop fabrication flaws in the welding of both primary and secondary ash lines resulted in significant air inleakage into both systems. The majority of all bolted flanges on the secondary ash lines were eliminated and replaced by welded connections. However, due to the design of the primary ash lines, bolted flanges could not be easily eliminated. All flanges were reworked and the system returned to service in December 1991 with no air inleakage. Air inleakage continues to be a problem now due to thermal cycling of the flange bolts. A program is presently underway to eliminate as many primary ash line bolted flanges as possible.

Gas Turbine

The gas turbine has experienced a measurable amount of erosion after 2100 hours of coal fired operation. Periodic inspections have shown that normal unit operation produces very little erosion; however, when cyclone ash removal lines plug the ash loading and erosion rate increase. The most significant erosion has occurred when a primary cyclone ash removal line plugs. In such an event, the corresponding secondary ash removal line is overwhelmed and quickly plugs. The primary cyclone normally collects 98% of the ash in the gas and the secondary collects approximately 33% of what remains. So when an entire string plugs, the gas turbine dust loading increases ten fold. A more important factor though, is the size of the particles. Each stage of cyclone collects successively smaller particles to where the normal secondary cyclone exhaust dust contains almost no particles larger than five microns in size. When an entire cyclone string plugs, the gas turbine is then exposed to particles as large as 250 microns. The erosion rate is much more sensitive to particle size than dust loading. Generally, when just a secondary cyclone ash removal line plugs the increase in erosion rate is minimal. However, during the 31 day run, the unit was operated with one secondary cyclone plugged and erosion was more than anticipated. The system configuration with six cyclone strings is being investigated as a possible cause for this increased erosion.

An ongoing problem with the gas turbine has been the bypassing of air from the high pressure compressor directly into the turbine. The present estimate of this leakage is approximately 3 times the design value for seal and cooling air flows. Given the normal compressor flow volumetric limitations, this leakage results in limiting unit firing rate, with the limit being worse with increasing ambient temperature. An area suspected of causing the leak was modified during the fall 1991 outage, however, this did not solve the problem. Investigations are continuing in identifying the cause of the leakage.

As mentioned previously, cracks were found in the root area on many of the low pressure turbine blades in March 1992. The cracks were attributed to high order resonant vibration. New blades designed to prevent this problem were installed before the unit was returned to service in May 1992.

UNIT PERFORMANCE

Unit performance tests were conducted in June 1992. The tests were conducted at full bed height with the maximum firing rate and bed temperature attainable. Preliminary test results for key parameters are presented in the following tabulation with expected values noted for comparison. Also noted is limited data from a run on February 21, 1992, during which approximately full load heat input was attained. This higher firing rate was possible due to increased gas turbine compressor capacity with a cooler ambient temperature and operation with lower excess air.

	6/14/92	Expected	2/21/92
Unit Firing Rate (MWt)	190.3	206.3	205.1
Gross Unit Output (MW)	60.2	72.5	70.0
Mean Bed Temperature (°F)	1550	1540	1579
Main Steam Flow (klb/hr)	395	442	432
Sulfur Retention (%)	92.6	90.0	93.1
Ca/S Molar Ratio	2.05	2.00	2.17
Predicted at 90% Retention	1.82	-	1.87
NOx Emissions (Lb/MMBtu)	0.18	0.5	.15
Combustion Efficiency (%)	99.4	98.0	-
Economizer Gas Outlet Temp (°F)	419	355	428
Air Flow to Combustor (klb/hr)	593	655	-
Excess Air (%)	20.1	25.0	13.3

Firing rate was limited due to a combination of air delivery and in-bed tube bundle absorption capabilities. The steam flow was impacted by both in-bed and economizer absorption deficiencies. The gross unit output was affected by all of the above plus a reduced steam cycle efficiency.

SUMMARY

The Tidd PFBC Demonstration Plant has completed over 2100 hours of coal firing operation while meeting its environmental performance objectives. With the 31 day continuous run, the unit has now met its reliability objectives. Additional testing scheduled for the remainder of the three year demonstration period will serve to assist in the establishment of the design basis for future commercial PFBC plants.

The main operating problems prior to this year's successful runs were attributed to the coal preparation and cyclone ash removal systems. Our experience to date emphasizes the importance of the coal preparation system in providing reliable coal injection and proper combustion and the importance of the cyclone ash removal system in ensuring sufficiently clean gas for gas turbine survivability. While refinement of all PFBC systems is likely, the cyclone ash removal and coal preparation systems will require the most significant efforts for commercialization of the PFBC technology.

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