AMERICAN ELECTRIC POWER PRESSURIZED FLUIDIZED BED COMBINED CYCLE TECHNOLOGY STATUS

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Keywords: Clean Coal Technology, Pressurized Bubbling Bed, Combined Cycle

INTRODUCTION

The Ohio Power Company's Tidd Pressurized Fluidized Bed Combined Cycle (PFBC) program continues to be the only operating PFBC demonstration program in the nation. The 70 MWe Tidd Demonstration Plant is a Round 1 Clean Coal Technology Project constructed to demonstrate the viability of PFBC combined cycle technology. The plant is now in its fourth year of operation. The technology has clearly demonstrated its ability to achieve sulfur capture of greater than 95%. The calcium to sulfur molar ratios have been demonstrated to exceed original projections. Unit availability has steadily increased and has been demonstrated to be competitive with other technologies. The operating experience of the first forty-four months of testing has moved the PFBC process from a "promising technology" to a viable, proven option for efficient, environmentally acceptable base load generation.

Funding for the $210 million program is provided by Ohio Power Company, The U.S. Department of Energy, The Ohio Coal Development Office, and the PFBC process vendors - Asea Brown Boveri Carbon (ABBC) and Babcock and Wilcox (B&W).

PLANT DESCRIPTION

The project involves the repowering of a 1940's vintage pulverized coal plant with PFBC components. The original Tidd plant consisted of two 110 MWe steam turbine generators supplied with steam by conventional coal fired boilers. The unit 1 steam turbine was repowered at approximately 50% capacity by the addition of a PFBC combustor steam generator and a gas turbine exhaust economizer. Other additions included in the AB scope of supply were the gas turbine and generator, the coal preparation system, the coal and sorbent feed systems, the gas cleaning system, and the cyclone and bed ash removal systems. The major balance of plant improvements included the addition of an electrostatic precipitator, combustor building, bed ash and cyclone ash silos, and sorbent preparation facilities. Modification of the coal and sorbent storage areas and a revamped control room completed the needed improvements for the conversion. The remainder of the balance of plant utilized the original Tidd balance of plant components and systems.

The PFBC Power Island (Figure 1), which was incorporated into the existing plant, was designed to provide 440,000 pounds per hour of steam flow at 1300 psia and 925°F. Plant generation output was expected to be 72.5 MWe gross (57.1 MWe from the steam turbine generator and 15.4 MWe from the gas turbine generator).

Air, at approximately 175 psia, is provided to the combustor by the gas turbine compressor through the outer annulus of a coaxial air/ gas pipe. Inside the combustor vessel, the air is ducted into the boiler where it fluidizes the bed materials and provides oxygen for combustion. The bed design temperature is 1580°F, which was established by the maximum acceptable gas turbine inlet temperature. This temperature is well above the minimum coal combustion temperature and provides sufficient margin to preclude melting of the coal ash constituents. In addition, this temperature is conducive to a relatively high reaction rate for SO_2 capture by direct sulfation of the calcium carbonate in the sorbent, while being well below the temperature at which alkalies vaporize and present a corrosion problem for the gas turbine. Formation of thermal NOx is essentially nil due to the low combustion temperature and the reduction of much of the NOx formed from nitrogen in the coal to N_2 and O_2 at char sites in the bed. Seven parallel strings of gas cleaning cyclones remove 99% of the ash elutriated by the gas leaving the bed. Six of the strings consist of a primary and a secondary cyclone, the seventh is comprised of a primary cyclone in series with an experimental ceramic Advanced Particle Filter (APF).

All of the cyclones are located in the combustor vessel. The APF is located outside the combustor in a separate pressure vessel. The gas from all seven strings is combined inside the pressure vessel and routed to the gas turbine via the coaxial air/gas pipe. The gases are expanded through an ABB Stal GT-35P gas turbine, which produces shaft power to run the gas turbine compressor (approximately 2/3 of the power at full load) and to drive the gas turbine generator (remaining 1/3 of the power). The turbine exhaust gases then pass through the economizer where excess heat is transferred to the feedwater and then through the electrostatic precipitator for further particulate collection. The gases then are ducted to Cardinal Unit No. 1 where they are combined with that unit's exhaust stream and exit to atmosphere via the Cardinal stack.

The steam cycle is a Rankine cycle with a subcritical once-through boiler. Condensate is heated by two stages of low pressure heaters and a gas turbine intercooler as it is pumped to the deaereator. A single high pressure heater and the turbine exhaust gas economizer raised the final feedwater temperature to approximately 480°F. The feedwater then passes through the boiler bottom hopper and furnace wall enclosures where additional subcooled preheating occurs. The feedwater then enters the in-bed evaporator tubes where the steam is generated and attains a slight degree of superheat. The steam then passes through the in-bed primary superheater, is attemperated and attains final steam temperature in the in-bed secondary superheater. At steam flows below 40% capacity, a circulation pump maintains sufficient flow rate through the evaporator circuits for cooling protection. The resultant moisture in the evaporator outlet steam is separated by centrifugal action in a vertical separator.

Coal is injected into the fluidized bed as a paste nominally containing 25 percent water by weight. Raw coal of 3/4 inch top size is fed to a double roll crusher which reduces the material to minus 1/4 inch. The crushed coal is conveyed to a screen to collect oversized material then to a mixer where water is added to make the paste. A recycle line, which is located upstream of the screen, returns a portion of the material to the crusher. Recycle is regulated to attain a sufficient quantity of coal fines, which are necessary to make a cohesive and pumpable coal paste. The paste is fed from the mixer into two interconnected surge tanks which supply six hydraulically driven piston pumps. These pumps feed the paste to individual fuel nozzles which deliver the paste into the fluidized bed just below the tube bundle.

The sorbent, which is generally dolomite, is crushed to minus 1/8 inch size and dried in a hot air swept hammermill crusher. This material is then injected into the fluidized bed via alternating dual lockhoppers that feed a dilute phase pneumatic transport system. The original transport system design splits the flow into two feed nozzles, however, the system has recently been modified to provide a total of four feed nozzles.

Material is drained from the bed to maintain the bed level. This "bed ash" accounts for approximately 40% of the total ash and is generally 99% larger than 60 mesh (250 microns). The ash is drained in a controlled manner by gravity via two parallel lockhoppers. Material elutriated from the bed and collected in the cyclones, approximately 60% of the ash, is generally 99% smaller than 60 mesh. This "cyclone ash" is removed by means of a pneumatic transport system which depressurizes and cools it.

BED PROCESS FINDINGS

Post-Bed Combustion

Initial operation of the unit revealed that combustion was occurring beyond the bed resulting in excessively high temperatures of the gas in selective cyclone strings and in the primary cyclone dip legs. The dip leg combustion was attributed to excessive unburned carbon carryover; whereas, the gas stream combustion was attributed to carryover of unburned volatiles. Both of these phenomenons were attributed to high localized fuel release combined with rapid fuel breakup and devolitization. Insufficient oxygen in these localized regions resulted in plumes of low O_2 gas with unburned volatiles and fine char. This was documented through oxygen measurements taken in the freeboard above the fuel nozzle discharge points. This problem was minimized through improved fuel splitting, installation of a steam induced freeboard gas mixing system, and improvements in the coal paste quality. The latter factor proved to have the greatest impact on reducing the degree of post bed combustion.

Recently, the unit has operated for extended periods with no signs of post bed combustion. However, upsets in coal paste preparation still result in upward swings in freeboard gas temperature. Such swings pose a potential trip risk at full bed height due to excessive gas turbine temperatures. At lower bed heights, these swings are not a problem, since the freeboard temperature runs well below the bed temperature due to the convective cooling action of the tubes above the top of the bed. The post bed combustion phenomenon is understood to the extent that operations personnel are able to monitor plant conditions and take early action to prevent or mitigate such occurrences.

Sinter Formation

The formation of small quantities of hollow egg shaped agglomerates, in the range of 1 - 2 inches in size (Sintering), has been observed throughout the operation of the unit. However, these did not pose a major operating problem at low bed levels, since the formation rate was slow and sinters drained from the bed at a rate which prevented any significant buildup. In late 1993 and early 1994, sintering became a significant operating problem. The rate of sinter formation increased greatly when the unit was operated at higher bed levels. At these higher formation rates, sinters accumulated in the bed causing bed conditions to deteriorate. Uneven bed temperatures, decaying bed density, and a reduction in heat absorption are common symptoms of bed sintering.

Initial speculation as to the cause of high load sintering focused on the higher local heat release associated with higher loads and insufficient fuel splitting. Modifications were made to both the fuel nozzles and the fuel distribution baffles to improve mixing. However, no significant improvements were observed. The hypothesis that poor bed mixing and less than ideal fluidization were key contributors was subsequently developed. A series of performance tests were proposed to demonstrate that better mixing would significantly reduce sintering. Improvements in fluidization were achieved by reducing the size consist of the dolomite feed, thereby reducing bed size consist, while maintaining fluidizing velocity constant. The introduction of finely crushed dolomite (-12 mesh) versus the normal coarse crush (-6 mesh) significantly reduced sintering to the extent that full bed temperature of 1580^{0}F could be maintained with no evidence of sintering.

The most severe incidents of sintering all occurred when feeding limestone. It is postulated that the reduced amount of MgO in the limestone may contribute to the uncontrolled sintering. The mechanism for this sintering is likely fluxing of the potassium-alumina-silicate clays in the coal ash by calcium from the sorbent. The nuclei of the sinters appear to be coal paste lumps which become sticky and collect bed ash on their surface. The coal then burns away, leaving the coal ash to react with the bed material. The less aggressive sintering with dolomite is explained by the fact that increased quantities of MgO tend to raise the melting temperatures of $CaO\text{-}MgO\text{-}Al_2O_3$ mixtures. In evaluating the sintering problem, it must be recognized that the extremely low ash fusion temperature of the Pittsburgh No. 8 coal burned at Tidd is likely a major contributing factor to sintering.

UNIT PERFORMANCE

Testing has progressed significantly since completion of the first three years of operation. The improved unit availability has provided the opportunity to conduct a greater number of varied performance tests than was previously possible. The most recent series of tests, were devised to address sintering issues by reducing the size consist of the bed. The finer sorbents, which were specified and purchased with a narrow size consist range, proved to be successful in addressing sintering while at the same time demonstrating exceptional improvement in the Ca/ S molar ratios.

The data clearly shows a significant improvement in sulfur capture resulting from the injection of finer dolomitic material as a the sorbent. The improvement in performance is significantly greater than can be explained solely by the larger sorbent exposed area due to the finer material. The noted improvement in performance must also be the result of significant improvements in bed fluidization and mixing. Especially when a number of other recorded system parameters such as steam generation and bed/evaporator temperature profiles also point to enhanced bed dynamics.

Performance testing has been limited to approximately 115 inches due to summer limitations on the gas turbine. However, overall testing has provided a sufficient basis to confirm the correlations, previously developed at Grimethorpe, thereby permitting extrapolation of the data to varied temperatures, bed heights, and sulfur captures. Figures 2 and 3 show sorbent utilization (Ca/S) versus bed height for 90 and 95 percent sulfur capture.

The affect of sorbent feed size consist on sorbent utilization is clearly seen. Reducing sorbent size consist from coarse sorbent (-6 mesh) to finer sorbent (-12 to -20 mesh) results in significant increases in sorbent sulfation and therefore reduced sorbent feeds to achieve a predetermined level of sulfur capture. In addition to sorbent size consist effect on sorbent utilization, Figures 3 and 4 show the impact of sorbent reactivity. National Lime Carey dolomite (NL) has generally been demonstrated to be less reactive than the Plum Run Greenfield dolomite (PRG).

CONCLUSION

The Tidd PFBC Demonstration Plant has now achieved over 9921 hours of coal fired operation. Approximately 3865 hours, including the longest continuous run of 1070 hours, were achieved during the last ten months of operation. Unit availability during this period was approximately 52%.

A total of 62 performance tests have been conducted to date. Eleven tests were completed during the latest run. Test objectives during the run were aimed at reducing bed sintering and improving sorbent utilization. The tests were conducted using -12 to -20 mesh sorbent. The finer sorbent was expected to improve bed mixing and fluidization, thereby mitigating sintering and improving sorbent utilization. Bed conditions improved significantly and operation at 1580^0F bed temperature was achieved with little, if any, bed sintering. Performance testing was completed at 1580^0F, 115 inch bed level and 90% sulfur capture. The results showed a marked improvement in sorbent utilization, Ca/S molar ratios around 1.3 were indicated. This data extrapolates to Ca/S molar ratios, at full bed heights, of 1.2 and 1.5 for 90% and 95% sulfur capture respectively.

In addition to improved sorbent utilization, the unit demonstrated better heat transfer than had previously been achieved as well as a more homogeneous bed temperature distribution.

The reliability of PFBC has and continues to be demonstrated. The process, which was initially demonstrated in early operation, has been refined and optimized to the point were PFBC is competitive with all other technologies for both low and high sulfur coals. Expected enhancements of both systems and process are expected to further improve sorbent utilization and system performance beyond the levels already achieved while continuing to demonstrate the service life of both the gas turbine and the boiler tube bundle. The process has been demonstrated to be environmentally sound, cost effective, and capable of achieving the reliability and availability required in a power generating unit. Commercial deployment remains the only hurdle left to PFBC technology.

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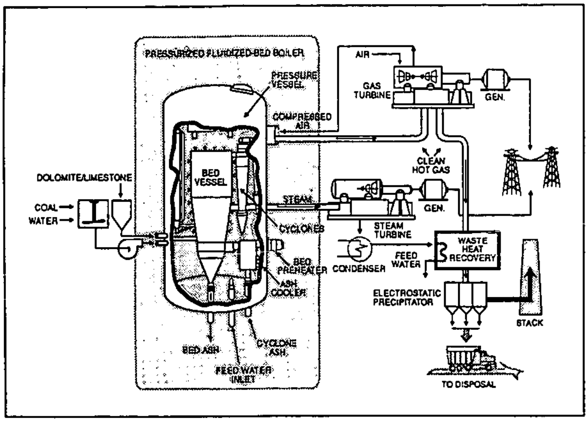

FIGURE 1 - TIDD PFBC COMBINED CYCLE

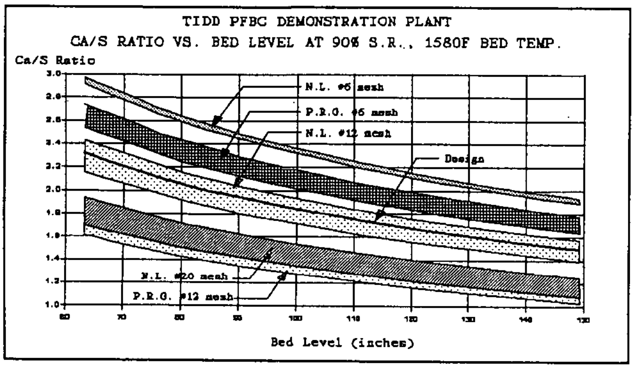

FIGURE 2

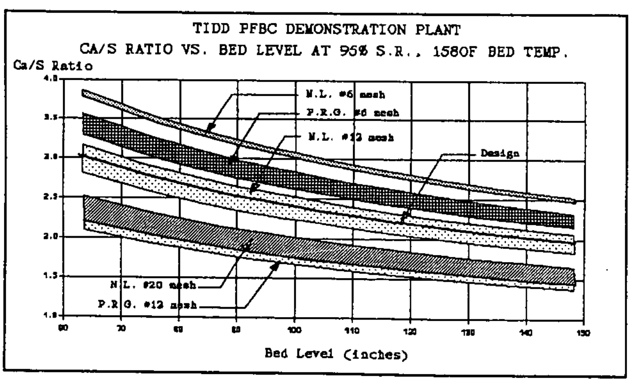

FIGURE 3