Design, Operation, and Performance of Commercial-Scale Carbon Burn-Out Facility

Introduction

Coal-fired power plants have significant economic and regulatory incentives to develop long-term plans for maximizing the value of their coal combustion products. Of those products, fly ash is generally considered to hold the highest economic potential, as its value as a mineral constituent in concrete is well documented and universally recognized. Concrete production represents a very attractive outlet for coal fly ash, as it combines demand for high quantities of ash with a willingness to pay attractive prices for ash meeting concrete-quality standards.

Specifications governing the use of fly ash in concrete set residual carbon limits, because residual carbon has the demonstrated property of adversely affecting chemical admixtures used to impart desired properties in concrete's plastic and hardened state. These admixtures are always used on projects requiring strict quality control of the concrete, for which the concrete producer receives a premium price. The producer will therefore refrain from using any ash that can cause problems for these high-value mixes.

Concrete specifications generally limit residual carbon in bituminous coal ash at levels of 3% to 6%. Prior to Low NO_x compliance modifications, a significant amount of a power plant's ash output would meet these standards. However, the various modifications designed to reduce NO_x emissions have frequently caused the unintended consequence of increasing residual carbon in fly ash. This, in turn, has led to a reduced supply of concrete-quality fly ash even in the face of strong demand from the concrete industry.

Given that the in-boiler environment is often not suitable for producing high-value fly ash, post-boiler fly ash beneficiation has significant appeal. Beginning in 1992, EPRI and EPRI members funded, through the Tailored Collaboration Program, development of the Carbon Burn-Out ash beneficiation technology. In 1999, this technology 'went commercial' with the first full-scale facility through start-up and running at design capacity. This facility was designed and constructed for South Carolina Electric & Gas and is located at their Wateree Station, a two-unit, 772 MW plant southeast of Columbia, SC.

Carbon Burn-Out (CBO) combusts residual carbon in fly ash, producing a very consistent, low carbon, high-quality fly ash. The process is continuous and is fueled solely by the residual carbon. Heat is recovered and sent back to the power plant that originally produced the high-carbon fly ash. The CBO process is an improvement on bubbling fluid bed technology.

An important feature of Carbon Burn-Out is heat recovery from the residual carbon's combustion. Heat is recovered from both the flue gas and the hot product ash. This recovered heat is returned to Wateree Station by heating a portion of the power plant's condensate stream. This portion of the condensate stream bypasses two existing feedwater heaters, thereby reducing the amount of extraction stream required, which in turn increases the quantity of steam available to the turbine-generator.

Phased Approach

Progress Materials, Inc. developed the Carbon Burn-Out technology with support from EPRI and EPRI members. A one-tph CBO pilot plant was constructed and operated as a 'proof-of-concept'. This plant, operating in a continuous mode, proved to be extremely useful in characterizing appropriate carbon combustion conditions for a wide range of ash sources. Generalizing, operations have shown that ash from any coal that can be successfully combusted in a dry-bottom (i.e. non slag-tap) pulverized coal furnace may be successfully processed in a CBO fluid bed. The product ash is then tested for concrete-application properties. As expected, all ash sources tested to date have fully met specifications after the residual carbon was combusted.

In 1997, fifty tons of Wateree high-carbon fly ash were processed in the CBO pilot plant. Data acquired during the test program on the Wateree ash provided the major design parameters for the full-scale Wateree plant. These data included optimal fluidization velocities, combustion rates, appropriate temperature regimes, and heat exchange coefficients.

The CBO ash carbon content was less than 2%. Test results demonstrated that concrete mixes made with CBO fly ash replacing varying percentages of Portland cement had nearly identical plastic and hardened characteristics to control mixes containing only cement. In short, the CBO fly ash provided significant benefits to the concrete mixes without undesirable 'side effects'. Determining the air entraining characteristics of the CBO fly ashes was given special emphasis. Laboratory concrete testing showed that CBO fly ash had consistently superior air entraining characteristics. Field testing confirmed the laboratory results.

Following the pilot plant tests, South Carolina Electric & Gas contracted with Progress Materials to provide a Carbon Burn-Out facility at Wateree Station. Initial site work began in December 1997 on a CBO plant designed to process 180,000 tpy of ash. Start-up activities began in mid-1998, and commercial operations began in early 1999.

CBO Plant Design

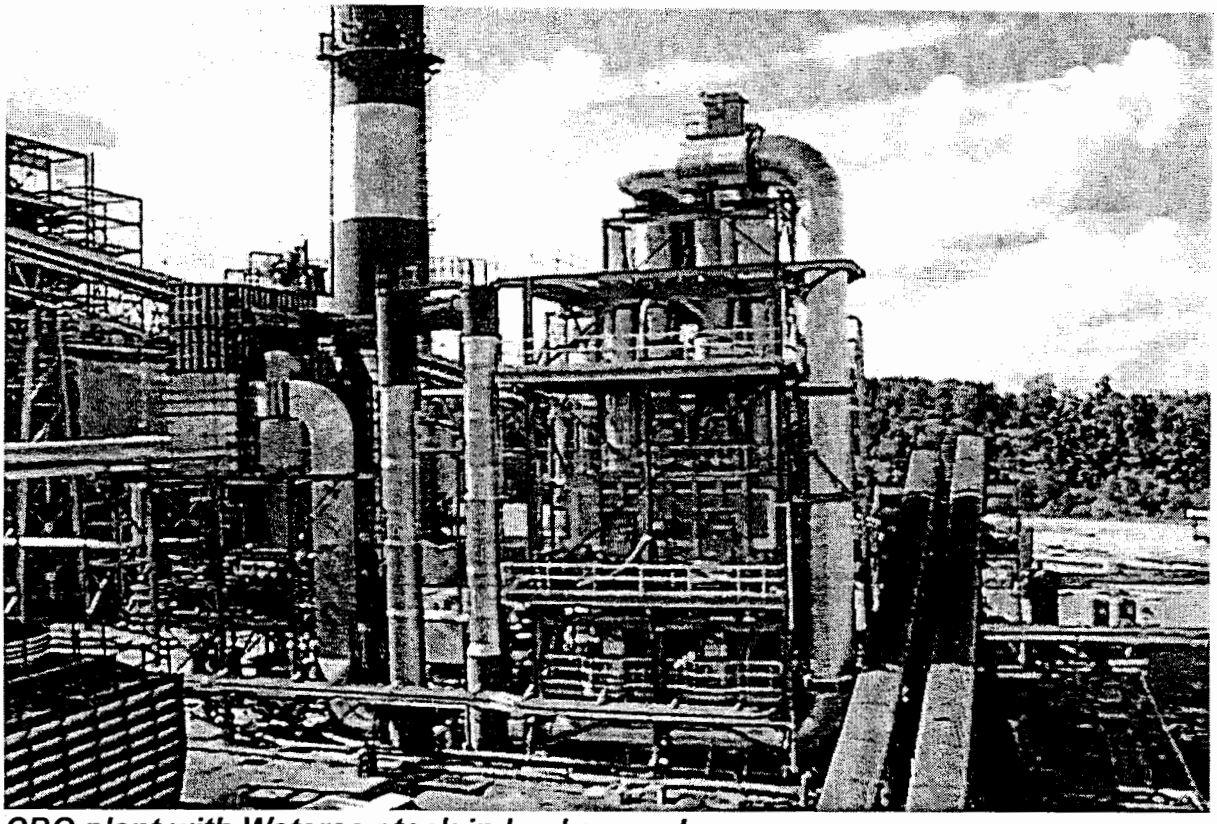
The philosophy governing the Wateree CBO plant design includes several important elements:

- maximize recovered heat to the power plant
- minimize Operating and Maintenance (O&M) costs
  - 'utility-grade' equipment
  - inclusive instrumentation
  - sophisticated control system
  - open plant layout for easy access
  - automated ash truck loading system
- maximize market value of Carbon Burn-Out product ash
  - high quality product, consistent quality
    - CBO process control keys off product ash quality, not feed ash LOI
    - Design provides for precise control of variables, immediate feedback
    - Long FBC residence time plus temperature control via cooled product ash provides 'smoothing' effect.
  - Product always available, accessible, traffic not interfering with plant operations

- Re-route ash truck traffic away from power plant
- Provide round-the-clock product loading without silo/scale-house attendant
- Two loading stations, both on scales
- 15,000 product ash storage to maintain product availability during outages

Referring to Figure 1, the CBO process flow may be easily summarized:

- high-carbon ash is pneumatically conveyed from existing silos to the CBO silo
- FD fan provides fluidization and combustion air to CBO fluid bed combustor
- feed ash is metered into the combustor
- carbon combusts in the FBC on a continuous basis
- material exits CBO combustor at 1350° F
  - product fly ash
  - flue gas
- heat exchange occurs between hot product ash + hot flue gas and condensate from the power plant
  - product ash and flue gas exits at < 300° F
  - heated condensate returns to power plant's feedwater heater system
- product ash is separated from flue gas via cyclone and baghouse
- ID fan maintains entire CBO system at a slight negative pressure, transports product ash through the heat exchanger, and transports cooled, particulate-free flue gas to power plant stack.
- product ash is pneumatically conveyed to the Storage and Load-Out Area



CBO plant with Wateree stack in background

Referring to the above photo, the Fluid Bed Combustor is within the tower at right-center. The heat exchanger is the inverted "U" in the center, and the product ash/flue gas separation takes place in the tower at left-center. FD and ID fans are behind the heat exchanger, as is the condensate pump and piping system. The CBO Control Room is just off the right border.

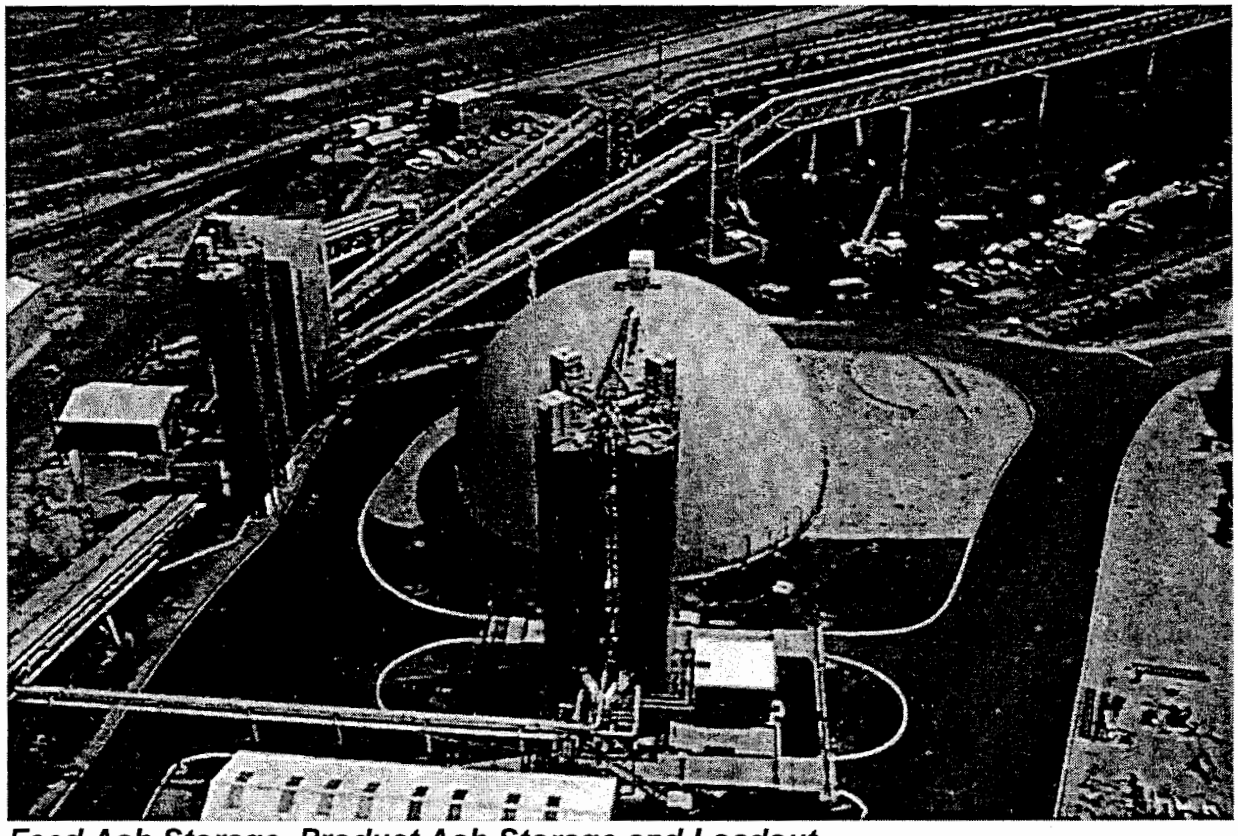
The CBO site at Wateree Station was selected for offering minimal duct runs while maintaining open access to all existing power plant systems. The ash product storage and load-out system is ~ 400' behind the photographer.

The CBO Fluid Bed Combustor (FBC) was designed and fabricated by DB Riley. The combustor is a refractory-lined steel box. The bed consists of only fly ash. For ease of maintenance, nearly all penetrations are through the roof. A start-up burner, fired by No. 2 oil, is in the air plenum below the bed. This burner is ramped down and then shut off once the bed reaches the residual carbon auto-ignition temperature of ~ 860° F.

CBO fluid bed temperature is precisely and automatically controlled by a 'recycle' system metering cooled product ash back to the FBC, where the returning product ash acts as a thermal load. The rate at which this ash is metered into the FBC is determined by the temperature profile in the fluid bed at any point in time -- increasing temperatures signal for more cool ash, declining temperatures signal for less. Pilot plant work first demonstrated this to be a very effective temperature control technique. It has the added benefit of 'smoothing out' minor variations in ash product LOI. In addition, an Exhaust Gas Recirculation (EGR) system has been added since initial

operations commenced and provides significant additional control, especially for enhancing turndown capability.

Environmental permitting for the Wateree CBO project proved quite straightforward. There is no solid or liquid waste stream from the CBO process -- all incoming high-carbon ash exits as a combination of product ash and flue gas. Wateree's heat rate is materially improved, resulting in less coal combusted for a given amount of electricity produced. Therefore overall site emissions are less. Fly ash disposal at Wateree is minimized.



Feed Ash Storage, Product Ash Storage and Loadout

The left side of the photograph above shows two 250 ton silos that receive high-carbon fly ash from other power stations to be processed in CBO Wateree. To date, these have been used to receive ash from SCE&G's McMeekin and Urquhart Stations, although ash from other stations has been received and processed as well. Ash from these silos is transported pneumatically to the CBO feed silo located directly above the fluid bed. Ash from the two Wateree units is pneumatically fed from an existing silo on the site in the same manner. Note that the ash receiving and load-out areas were located on the site so as to avoid interference with normal power plant and coal handling operations.

In the photo's foreground are four 250 ton product ash load-out silos, which receive ash pneumatically transported directly from the CBO plant, or from the storage

dome, or from both simultaneously. Ash loading and weighing is automated using an entry card system operated by the truck driver. Access is 24 hours per day, seven days a week. This system eliminates the need for load-out operators, and to date has functioned as designed.

The dominant structure in the rear is the new 120' diameter concrete dome. This dome, with its 15,000 ton ash storage capacity, was primarily intended to smooth out seasonal construction fluctuations. However, the enhanced operational flexibility provided by the dome has led to almost daily use, as sales of CBO low-carbon ash have exceeded forecasts. The dome features inward-sloping concrete floor over a fly ash structural fill. Aeration slides are mounted on the floor radially from the center. Fluidized ash enters pneumatic transporters at the center of the dome's floor and is transported to the specified load-out silo. Dome fluidization is by segments, with the pattern and timing being automatically performed by the CBO control system signaling motor-operated valves on the aeration manifold. To date, the filling, storing and reclaim systems all have functioned as designed.

CBO Plant Operations

Following pre-operational checkout, start-up, and de-bugging, Wateree CBO was placed into commercial operation in early January 1999. To date, the 1350° F operating temperature has proven satisfactory at CBO Wateree for all ash sources processed.

Recovery of heat from CBO Wateree and application back to the turbine cycle in the power plant has functioned fully as designed. By the Fall of 1999, approximately 200,000 million Btu's have been directly recovered to the Wateree units, or approximately the heating value of 8,000 tons of coal that did not need to be purchased, transported, stored, and combusted for the same amount of electricity produced.

Two people per shift perform CBO plant operations, including quality control on the product ash being shipped.

The Wateree CBO fly ash product is finer in particle size than the high-carbon feed ash, and is very similar to the fineness of low carbon fly ash produced by the Wateree units before Low NO_x burners. The CBO product fly ash shows no signs of agglomeration. The fly ash has performed very well in the concrete marketplace and is viewed as a premium product. By the Fall of 1999, approximately 100,000 tons of product ash has been shipped.

Future Fly Ash Challenges

Wateree Station is now fitted with low NO_x burners and complies with current regulations. However, further reductions in NO_x emission limits may well require the application of either Selective Catalytic Reduction (SCR) or Selective Non-Catalytic Reduction (SNCR) technology. Both are known to deposit ammonia onto the fly ash. Even at relatively low levels, ammonia-on-ash presents significant marketing problems and perhaps occupational health and safety issues as well.

Progress Materials has undertaken a CBO pilot plant test program on high-carbon fly ash containing ammonia. This work has demonstrated that product ash from the Carbon Burn-Out fluid bed is both low-carbon and totally ammonia-free.

Summary

- Carbon Burn-Out has proven effective and efficient in producing a consistent, very high quality fly ash
- The plant has demonstrated its ability to produce a consistent 2% LOI product from a range of feedstock carbon contents and sources
- The CBO process flow was successfully enhanced so as to provide a much greater operating range than originally designed
- Heat recovery back to the power plant functions fully as designed
- CBO product ash quality meets or exceeds applicable specifications and the concrete market's requirements
- Ammonia-on-ash is a major concern for the near future. Carbon Burn-Out produces ammonia-free fly ash

Further Information

For more information regarding Carbon Burn-Out technology and its applications, contact Ari Huttunen at EPRI, Palo Alto, CA, (650) 855-2661, or Tom Boyd, EPRI, Charlotte, NC, (704) 547-6033.

Further Reading

"Recent Results From Fly Ash Beneficiation by Carbon Burn-Out." EPRI TB-103832. July 1994.

"Design, Operation, and Testing of the Fly Ash Carbon Burn-Out Pilot Plant." EPRI TR-102429. April 1996.

"Fly Ash Carbon Burn-Out at TVA's Colbert and Shawnee Stations – Site Specific Application Study." EPRI TR-105825. April 1996.

"Evaluation of Carbon Burn-Out Technology Applied to Rice Hull Ash." EPRI TR-106061. April 1996.

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