Carbon Burn-Out
An Update on Commercial Applications

2001 International Ash Utilization Symposium
University of Kentucky Center for Applied Research

By:
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Introduction

Fly ash from pulverized coal plants can be a valuable mineral admixture in concrete provided it meets quality criteria such as size consist and low carbon and ammonia content consistently. Meeting all of these parameters reliably is an expanding challenge in an increasingly complex world. Ash quality problems lead directly to increased disposal, which is beginning to look even more ominous from an environmental/regulatory perspective.

Application of low-NOx burners in past years as a result of Clean Air Act requirements drove residual carbon levels in fly ash higher. To the extent that the ash was already marginal in meeting customer demands for low LOI, cleanup of that ash was needed to maintain, and even improve, the market for that ash and avoidance of disposal.

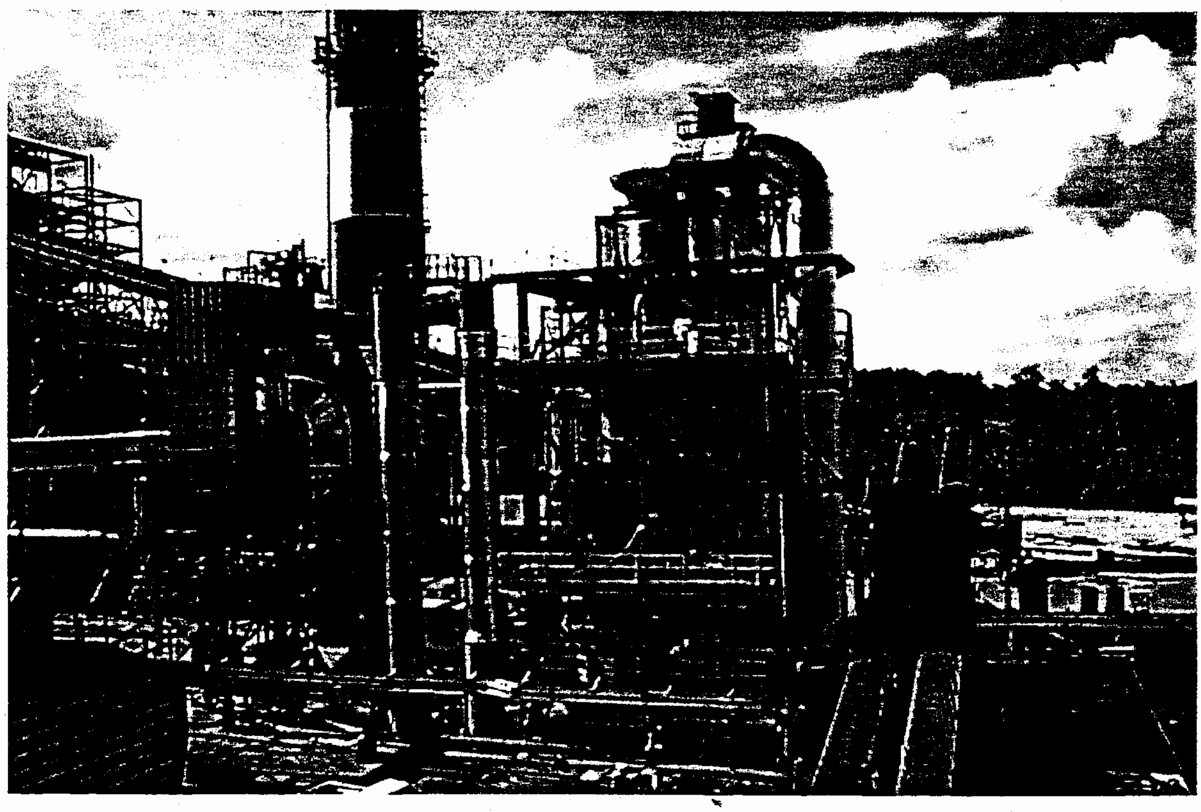
In addition, ammonia injection is used in some cases to enhance electrostatic precipitator performance, and is being applied widely in Selective Catalytic Reduction (SCR) and Selective Non-Catalytic (SNCR) Flue Gas Treatment Systems to meet more stringent NOx standards than can be met solely with low NOx burners. Ammonia contamination resulting from such systems further exacerbates the situation, and removal of ammonia is needed for any ash containing more than about 50-100 PPM (current range of limits being considered) if it is to be used in concrete applications.

Progress Materials, Inc. (PMI); a subsidiary of Progress Energy Corporation (which also owns Florida Power and Carolina Power and Light) has long recognized the benefits of using combustion technology to transform high-carbon fly ash into a marketable product. PMI developed a proprietary technology and patented process called Carbon Burn-Out (CBO) to not only accomplish carbon reduction, but also recover the energy associated with this carbon to improve the overall power plant efficiency of the host ash source. As a side benefit, and without modification to the CBO, any ammonia on the ash is reduced to non-detectable levels.

South Carolina Electric and Gas CBO

The first full-scale application of CBO went into commercial service at the Wateree Station of South Carolina Electric and Gas in January 1999. Wateree is a two-unit, 772 MW plant located southeast of Columbia, SC. Design basis of the CBO installation is to process 180,000 tpy of ash with an average of 12.5% LOI.

A summary overview of that installation follows:



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 about 400 feet behind the photographer.

The CBO Fluid Bed Combustor (FBC) was designed and fabricated by DB Riley, using PMI's process design parameters. The combustor is a refractory-lined steel box divided into two cells to allow precise process control. 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 about 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 the same or less. Fly ash disposal at Wateree is minimized.

CBO Experience to Date:

Over 19,000 tons per month of premium fly ash have been sold from the Wateree CBO. Feed ash LOI to the CBO has ranged from 6.5 to 18%, averaging ~10-11%, while product ash has consistently averaged 2.5%, as targeted, and performed exceptionally well in the marketplace. It should be noted that product LOI can be lowered to a target of 2% or less if desired. However, experience with product performance on CBO ash yields most acceptable results at the current target.

Recovery of heat from CBO Wateree and application back to the turbine cycle in the power plant has functioned fully as designed.

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

The Wateree CBO fly ash has the same superior air entraining characteristics demonstrated by the bench model and pilot plant product ash, even at slightly higher LOI than observed in the preliminary testing. Hardened concrete testing confirms the good strength-producing characteristics expected of Class F fly ash. There is no significant correlation between LOI and the concrete strength results obtained to date.

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 or other detrimental properties. The fly ash has performed very well in the concrete marketplace and is viewed as a premium product.

Santee Cooper CBO

Santee Cooper's Winyah Generating Station will be the site of the next CBO, slated to be in service in 2002. Winyah consists of four – 280 MW units located near Georgetown, South Carolina. Design basis for the CBO is to process 210,000 tons of fly ash per year, approximately 170,000 of which will come from Winyah. The remainder, approximately 70,000 tons, will come from Santee Cooper's Grainger station, which has two – 88 MW units. Combined LOI of the feed ash is expected to be 16%.

Among the design enhancements to be incorporated are improved feed ash blending facilities, elimination of above-bed burners (which were found to be unnecessary) and an integrated fluid bed rather than two separate cells. Also, we have designed an improved air distribution plate seal system, and eliminated "double dump" valves used to control ash flow to the exhaust duct for transport to the cyclone collector/baghouse. All of these improvements favor an even more economical means of using this technology.

Future Implications

Further reductions in NO_x emission limits will require wide 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 conducted a CBO pilot plant test program on over 25 tons of high-carbon fly ash containing several hundred parts per million of ammonia. This work demonstrated that, even without process flow changes, product ash from the Carbon Burn-Out fluid bed is both low-carbon and ammonia-free. Long residence times (particles average about 45 minutes in the fluid bed) together with average temperatures in the 1350° F range promote those reductions.

Summary

- Carbon Burn-Out has proven effective and efficient in producing a consistent, very high quality fly ash
- The Wateree CBO plant has demonstrated ability to produce a consistent 2.5% 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
- Plant storage and loadout features significantly enhance market flexibility
- 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
- The Winyah CBO plant will go into service in 2002, incorporating several design improvements from "lessons learned" at Wateree
- Ammonia-on-ash is a now major concern. Carbon Burn-Out produces ammonia-free fly ash

Carbon Burn-Out, Commercialization and Experience Update

For:

2001 Conference on Unburned Carbon on Utility Fly Ash

By:
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Progress Materials, Inc.

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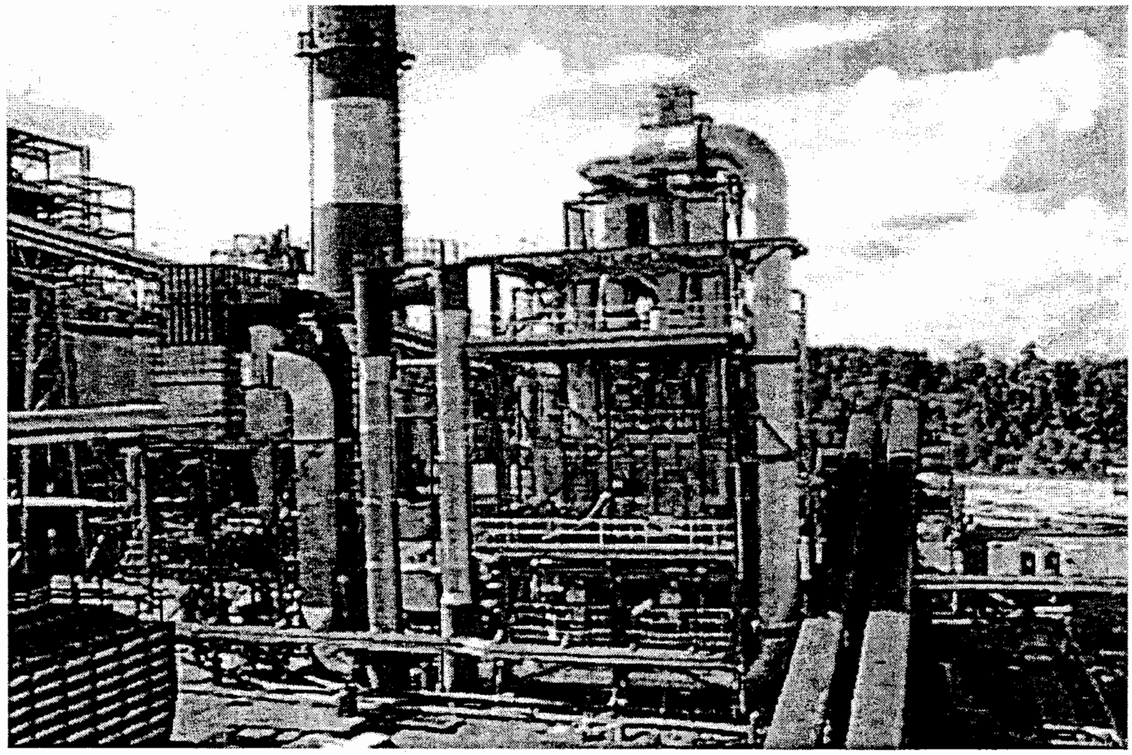

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Second Unit Design Enhancements

Santee Cooper's Winyah Station will be the site of the next CBO, slated to be in service in 2002. Among the design enhancements to be incorporated are improved feed ash blending facilities, elimination of above-bed burners (which were found to be unnecessary) and an integrated fluid bed rather than two separate cells. Also, we have designed an improved air distribution plate seal system, and eliminated "double dump" valves used to control ash flow to the exhaust duct for transport to the cyclone collector/baghouse. All of these improvements favor an even more economical means of using this technology.

Future Implications

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.

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EPRI

technical brief

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

Combustion By-Product Use Target

Introduction

Coal-fired power plants have significant economic and regulatory incentives to maximize the value of their combustion by-products. Of those by-products, fly ash is generally considered to hold the highest economic potential, especially as a replacement for up to 30% of the cement used in concrete.

Concrete specifications generally limit unburned carbon (UBC) in fly ash to 3 to 6%. Prior to the addition of combustion modifications for NO_x reduction, most power plants produced fly ash that met these specifications. However, in a number of cases, low-NO_x retrofits have increased the UBC levels above these limits. To counter this increase in UBC, EPRI has supported the development of the carbon burn-out (CBO) ash beneficiation technology since 1990, in collaboration with several members.

The CBO process combusts the residual carbon in fly ash, using the carbon as fuel. The combustor is a bubbling fluid bed, modified to operate at CBO process's thermal conditions (1350°F [732°C]) and improved to accommodate fly ash, which has a mean particle size of approximately 15 µm. Heat resulting from the carbon's combustion is recovered and returned in a usable form to the power plant.

Environmental permitting for a CBO project should be straightforward. There is no solid or liquid waste stream—all incoming high-carbon ash exits as a combination of salable product ash and flue gas. Heat rate is improved somewhat, resulting in correspondingly less emissions and coal combusted for a given amount of electricity produced.

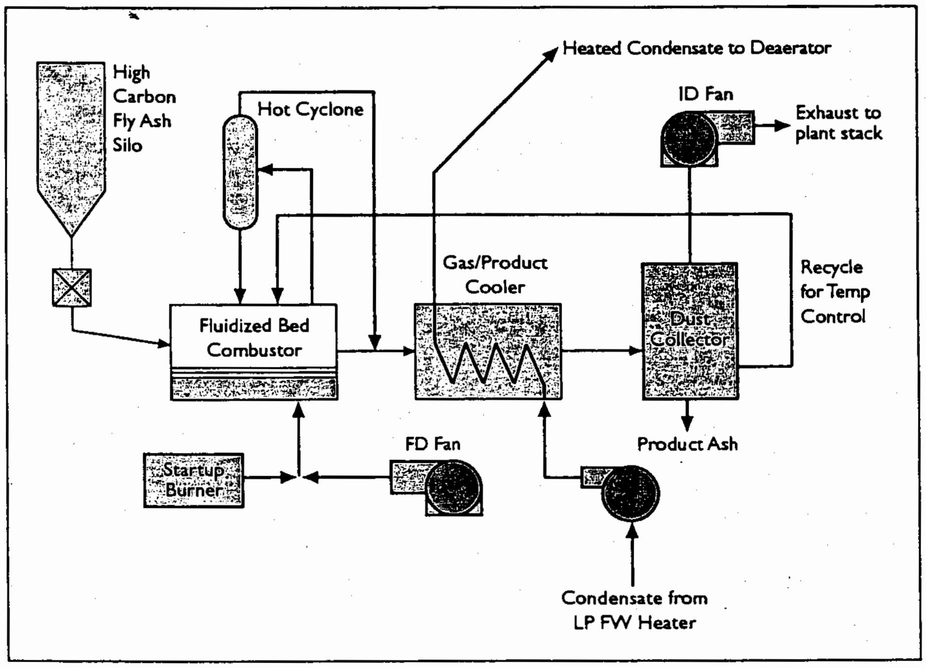

Figure 1. Simplified process flow diagram of commercial-scale CBO facility.

Phased Approach

CBO development proceeded in a phased fashion. To demonstrate proof-of-concept, the vendor, Progress Materials Inc. (PMI), constructed a one-ton-per-hour CBO pilot plant. 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. The tests showed that, generally, 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.

All ash sources tested to date have fully met the residual carbon specifications for concrete after processing by the CBO unit. However, CBO process economics favor sites where UBC levels are higher than ~7%, as this minimum amount of carbon in the ash is required for self-staining combustion without supplemental fuel. As CBO processes carbon, the size and, therefore, capital cost of the fluid bed and heat exchanger are determined after forecasting the amount of carbon to be combusted. Processing 12% UBC ash requires a larger CBO plant than processing the same quantity of ash at 8% UBC. Fluctuations in actual UBC are readily accommodated by controlling the ash feed to the CBO fluid bed so as to maintain ~ constant carbon feed rate. As with most processes, economics generally favor the largest plant that fits the ash supply and the market demand. Other factors affecting CBO economics are the selling price of the product ash and the value of the recovered heat.

The pilot plant successfully demonstrated that the CBO process could readily operate on a self-sustaining, continuous basis and could produce quality ash product from a wide range of ash sources. Information on the pilot plant work was disseminated to members through an on-site workshop, *Technical Brief* articles, and several published reports. In addition to demonstrating and developing process expertise, the CBO pilot plant has been used in six tailored collaboration test burn programs for EPRI members wishing to determine specific ash performance data, both for CBO combustion conditions and market surveys on the resultant product ash. Additionally, successful pilot plant test programs have been conducted on biomass ash, ash from coal and petroleum coke blends, and ash containing ammonia.

Full-Scale Carbon Burn-Out Plant

In fall 1997, EPRI member South Carolina Electric & Gas decided to build the first full-scale CBO plant to be located at Wateree Station, a two-unit, 772-MW plant southeast of Columbia, South Carolina. Important design characteristics and features of this plant include

- 180,000 tons per year of feed ash at 12% average UBC;
- 25-ton-per-hour at 85% capacity factor;
- 24-hours-per-day, 7-days-per-week operation;
- 2% UBC in the product ash;
- heat recovery via condensate heating ahead of the feedwater heaters; and
- new and expanded product ash storage and load-out facilities.

The operation principle of the commercial-scale CBO is shown in Figure 1 and can be summarized as follows:

- High-carbon ash is pneumatically conveyed from existing silos to the CBO silo.
- An FD fan provides fluidization and combustion air to the CBO fluid bed combustor.
- Feed ash is metered into the combustor (FBC).
- Carbon combusts in the FBC on a continuous basis.
- Material exits the CBO combustor at 1350°F (732°C):
  - Product fly ash
  - Flue gas from the combustion in the fluid bed
- Heat exchange occurs between the hot product ash plus flue gas and the condensate from the power plant:
  - Product ash and flue gas exit at < 300°F (150°C).
  - Heated condensate returns to the power plant's feedwater heater system.
- Product ash is separated from the flue gas by a cyclone and baghouse.
- An ID fan maintains the entire CBO system at a slight negative pressure; transports product ash/flue gas through the heat exchanger; and delivers cooled, particulate-free flue gas to the power plant stack.
- Product ash is pneumatically conveyed to the storage and load-out area.

The CBO fluid-bed temperature is automatically controlled by a "recycle" system that meters cooled product ash back to the FBC, where it 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, with the added benefit of "smoothing out" minor variations in ash product UBC.

The Wateree CBO plant was designed, permitted, and constructed during 1998, with startup beginning late that year. The unit began commercial operation in early 1999.

Initial Experience

Startup and first-year operations provided much useful information concerning actual plant performance vs. design.

Actual fly ash UBC levels were frequently less than had been forecast during project planning, resulting in higher-than-design processing rates. Rates of 45 tons per hour were frequently achieved, although sustained operations at those rates quickly consumed the stock of available feed ash. Further, the actual carbon combustion rate in the full-scale fluid bed was observed to be ~20% greater than that observed in the pilot plant. This higher rate meant that extra processing capacity was available.

Adding a controllable flue gas recirculation system in May 1999 allowed significantly improved turndown for the CBO fluid bed. This turndown was very useful for maintaining steady-state operations during periods in which only relatively low-carbon ash was available for processing. This feature allowed "load-following" in which the CBO operator would set the processing rate to closely match the incoming feed ash supply.

Energy recovery via preheating of the condensate prior to the feedwater heaters performed as designed. Wateree plant performance tests demonstrated that CBO heat recovery provided a 60 Btu/kWh heat rate improvement. This improvement is almost identical to that predicted by a PEPSE thermal systems model run and by a GE steam turbine study performed during preliminary design. The existing Wateree control system required no modification to accommodate the presence of heated condensate coming from the CBO plant.

Both planned and unplanned outages were fairly frequent during the first year of operation, due either to mechanical problems or lack of sufficient feed ash. Subsequent startups after these outages provided much insight into CBO fluid bed operations.

The as-built fluid bed combustor included both a below-bed startup burner and several above-bed burners. It quickly became apparent that above-bed burners were not required for startup, and they were subsequently removed from service.

Shutdown of the fluid bed involves stopping the ash feed and then the fluidization air. Absent of air,

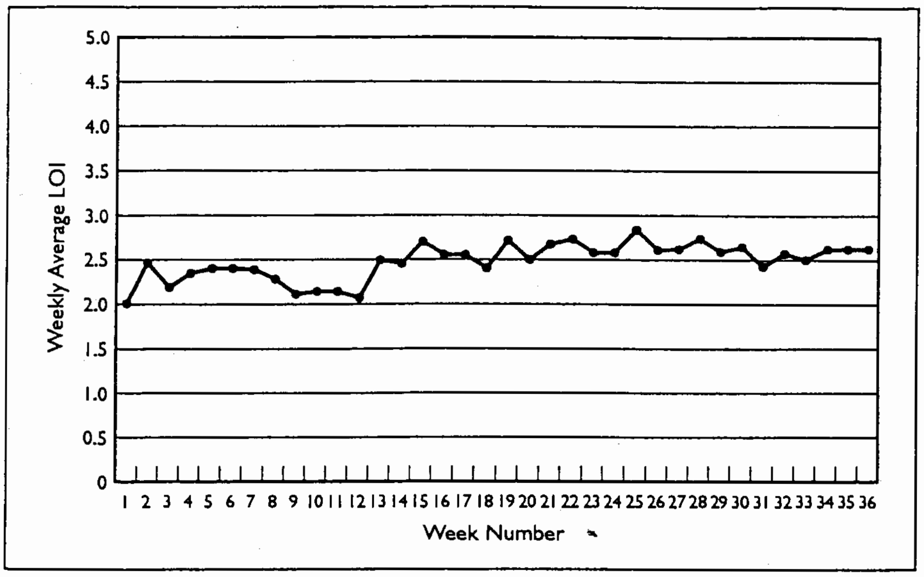

Figure 2. CBO Product Ash Weekly Shipment LOIs.

combustion of carbon in the bed immediately ceases. The bed loses fluidization and "slumps". In this slumped condition, the temperature profile degrades very slowly because ash is a good insulator and the fluid bed is heavily insulated. This heat retention enabled "hot starts"—a startup in which no supplemental fuel is required. Hot-start capability was demonstrated at up to 16 hours of downtime. With hot-start capability, steady-state operations are reached within 10 minutes of rolling the fans. Product quality is not affected, as only on-spec product ash leaves the fluid bed.

The hot-start benefit proved invaluable during periods of low feed ash availability. The CBO plant would intentionally cease combustion operations for several hours until sufficient feed ash became available, then quickly come back online.

After a series of field trials and discussions with concrete producers, the CBO ash product target was set at 2.5% LOI (LOI is an indicator of UBC and a more commonly measured property). This quality fully meets both ASTM specifications and concrete producers' more stringent requirements. Immediately upon introduction, Wateree CBO ash met this market specification. After one year, a two-tier market has developed, with CBO ash the "brand" name, and conventional fly ash occupying a second, lower-value tier.

Figure 2 shows daily averages of CBO ash truck shipment samples taken over a 36-week period in 1999. The degree of consistency shown here is appreciated by the concrete market, which places a limited value on ash of variable quality.

As it became clear during first-year operations that the Wateree CBO plant had a greater-than-design capacity, additional high-carbon Class F ash sources were located and shipped to Wateree when available. LOIs from these new sources ranged from 6.5 to 18% (see Figure 3). This higher-than-expected variation in UBC increased the level of attention required of the CBO operators to always produce the target LOI product. Operator staffing was set at two per shift, with all required product ash quality control being performed by the CBO staff.

An automated product ash sampling and measurement system was installed but unfortunately has yet to produce the accuracy and precision required for product ash quality control. Therefore, operators have to manually sample the UBC content of the product ash every other hour to control ash feed rate to the process. In 2000, the automated product ash sampling and measurement system will be reconfigured to sample and monitor feed ash LOI; this change is expected to allow automated measurement. In addition, the CBO feed ash receiving and transporting systems will be improved. Not originally designed for controlled blending, the feed ash silo systems will be enhanced in 2000 to allow both simultaneous feeds from two sources and short "bursts" of feed from multiple silos into the receiving silo. Both enhancements will provide a smoothing effect on incoming ash LOI.

The value of Wateree CBO ash was further enhanced by the storage and load-out system incorporated into the

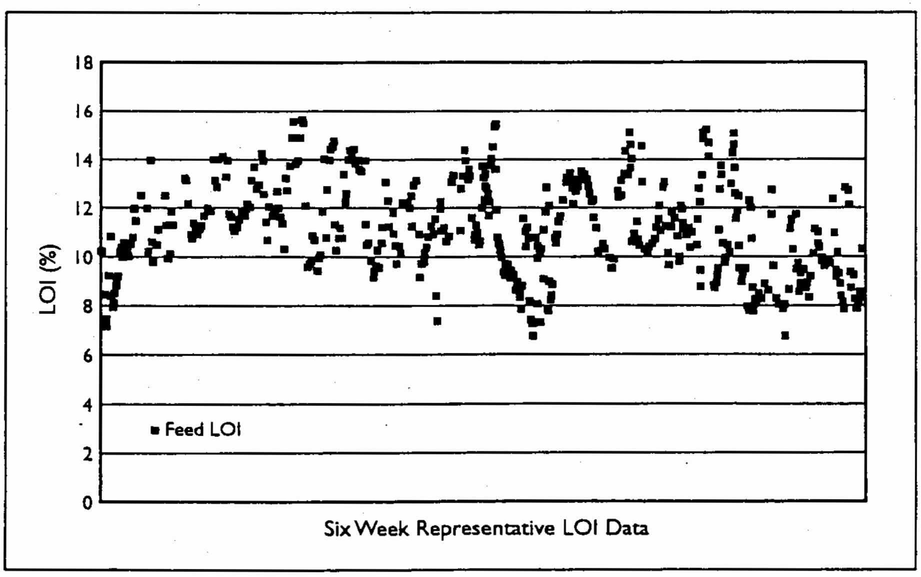

Figure 3. LOI of feed ash to CBO Plant.

project. The load-out and weighing system is automated and requires no operator. All functions are performed by the drivers using preauthorized access cards. The system is fully available on a 24-hours-per-day and 7-days-per-week basis.

A 15,000-ton ash product dome, as storage capacity, ensures ash availability during periods of low ash production and continuity of production during periods of high electricity generation but low product ash demand. The dome receives ash from the CBO plant and reclaims it to the load-out silos. All dome functions are remotely monitored and controlled by the CBO plant operators. The dome's sloped floor with air slides has proven effective at emptying the dome to a very low level.

Summary

The Wateree CBO plant is in full commercial production and meeting or exceeding design criteria. The CBO ash product has demonstrated consistently high performance and is the "brand name" in the market. Remote ash sources can be readily accommodated and processed, although operator staffing requirements may increase if the feed ash LOI is highly variable; some degree of LOI smoothing is built into the process to minimize the need for increased operator attention. The product ash storage and load-out system provides an important value-added feature while simultaneously minimizing plant labor requirements.

Several improvements will be made on subsequent CBO plants. These include elimination of several mechanical devices found to be redundant, improved air distribution plate packing, and inclusion of a flue gas recirculation system. The higher-than-expected carbon combustion rate will be used in plant design, which will result in a smaller fluid bed for the same ash throughput. A control system will be selected to take advantage of "smart" instruments and minimize field wiring. An additional level of modularization will be evaluated, with the goal of minimizing field erection time.

Future Work

Blending petroleum coke with coal is frequently very cost effective for scrubbed plants. Pet coke blending invariably results in high levels of unburned carbon in the fly ash. Pilot tests are showing that the CBO process will produce the target LOI product from these blends as it does from straight coal combustion.

Many coal-fired plants could soon be fitted with NOx reduction technologies (selective catalytic reduction [SCR] or selective non-catalytic reduction [SNCR] technology) that frequently have the unintended consequence of depositing ammonia on fly ash. High ammonia levels render the ash unmarketable and create odor problems for workers handling this ash. Additionally, permitting disposal of ash containing ammonia will be difficult. Pilot CBO tests have demonstrated this process's ability to completely remove ammonia from fly ash, in addition to combusting the residual carbon. Neither process modifications nor additional equipment are required.

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.

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Assessment of Impacts of NO_x Reduction Technologies on Coal Ash Use: Volume 1: North American Perspective. EPRI TR-106747-V1. November 1996.

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