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WHITE PAPER

DESIGN AND OPERATION OF FABRIC FILTER AND ELECTROSTATIC PRECIPITATOR HOPPERS WITH HIGH-CARBON ASH

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INSTITUTE OF CLEAN AIR COMPANIES, INC.

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The Institute of Clean Air Companies, Inc. (ICAC) is the national association of companies that supply stationary source air pollution monitoring and control systems, equipment, and services. The association was formed in 1960 as a non-profit corporation to promote the industry and encourage improvements of engineering and technical standards. The Institute's members are leading manufacturers of equipment to monitor and control emissions of particulate, VOC, SO_2, NO_x, air toxics, and greenhouse gases.

The Institute's mission is to assure a strong and workable air quality policy that promotes public health, environmental quality, and industrial progress. As the representatives of the air pollution control industry, the Institute seeks to evaluate and respond to regulatory initiatives and establish technical guidelines to benefit all.

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EXECUTIVE SUMMARY

With the Nation's coal-burning utilities facing tighter controls on mercury pollutants, the U.S. Department of Energy is supporting projects that could offer power plant operators better ways to reduce these emissions at much lower costs. Sorbent injection technology represents one of the simplest and most mature approaches to controlling mercury emissions from coal-fired boilers. It involves injecting a solid material such as powdered activated carbon (PAC) into the flue gas. The gas-phase mercury in the flue gas contacts the sorbent and attaches to its surface. The sorbent with the mercury attached is then collected by a particulate control device along with the other solid material, primarily fly ash. Recent events with TOXECON™ mercury control systems have highlighted the need to continue to investigate the balance-of-plant issues related to the injection of powdered activated carbon into a fabric filter.

Under a Department of Energy Clean Coal Power Initiative (CCPI) project, We Energies reported that in March 2006 they experienced overheating of a mixture of powdered activated carbon and Powder River Basin (PRB) ash in the hoppers of their new TOXECON™ baghouse at the Presque Isle Power Plant in Marquette, Michigan (Derenne, 2006). At this site, activated carbon is injected up stream of a pulse-jet baghouse that is located downstream of the existing hot-side electrostatic precipitators (HESP). The hopper ash was a mixture of about half PAC and half PRB ash by weight with a loss on ignition (LOI) of nominally 35%. Burning embers were found in the hoppers after several weeks of normal operation.

Carbon heating situations do not occur in all facilities. Approximately eighty U.S. waste-to-energy plants use carbon without incident and RWE Energy’s coal-fired power plant in Germany has been in operation since 1999 without any hopper thermal events or heating problems.

An investigation is ongoing to determine the design and operational issues that contributed to the event. The two foci of the investigation are to:

1. Determine the causes of the creation of burning embers in the baghouse hoppers.
2. Determine operational/design measures to minimize or eliminate the issue of ember creation in the baghouse hoppers.

Industry has an abundance of experience in the design and operation of particulate control systems with high-carbon ash. This White Paper summarizes the experience of members of the Institute of Clean Air Companies (ICAC) and also provides guidelines for Users that are considering process changes that may increase the carbon content of the fly ash.

EXAMPLES OF HIGH-CARBON ASH PROCESSES

Activated Carbon Injection for Mercury Control

Powdered activated carbon (PAC) injection at coal-fired power plants typically falls into three different configurations. The first is the common practice of injecting PAC into the ductwork upstream of an existing particulate collection device. When PAC is injected in front of the sole particulate collector, the fly ash from that device is combined with the PAC used to control mercury emissions and the increase in ash carbon content is typically less than 1% for a baghouse and less than 5% for an electrostatic precipitator (ESP).

The second configuration is injection of PAC with a dry scrubber and baghouse. The injection point of this system is usually upstream of the dry scrubber to allow increased residence time for the PAC to enhance mercury removal. The increase in loss on ignition (LOI) from PAC in this configuration is less than 1%.

The third set of configurations is the Electric Power Research Institute (EPRI) TOXECON™ process, where the majority of ash is removed prior to injecting PAC. TOXECON™ is an EPRI-patented process (U.S. Patent 5,505,766) for removing pollutants from combustion flue gas by injecting sorbent in between an existing particulate collector and a fabric filter (baghouse) installed downstream of the existing collector for control of toxic species. The TOXECON™ configuration, shown in Figure 1, allows for separate treatment, sale, or disposal of the ash collected in an ESP (99% or greater) and the ash/sorbent collected in the TOXECON™ baghouse.

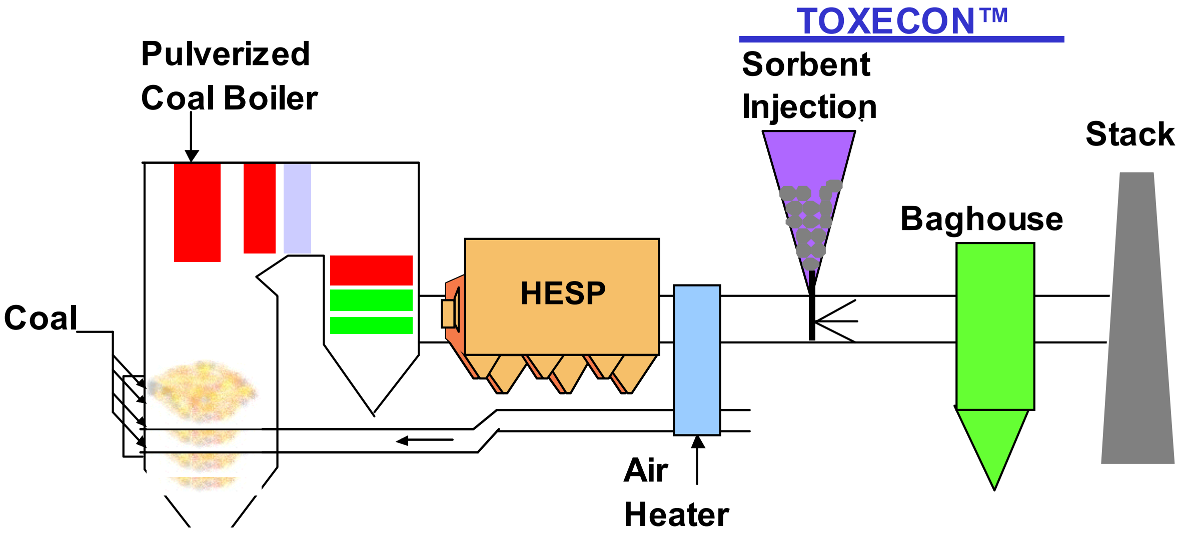

Figure 1. TOXECON™ Configuration.

In the TOXECON II™ configuration, shown in Figure 2, an injection grid is inserted between fields in an ESP. If the hopper collection system is segregated, the majority of the fly ash collected in the inlet fields can be treated separately, similar to the TOXECON™ configuration, and therefore any beneficial use of this portion of the ash is retained. Ash collected from downstream fields after PAC injection in these configurations typically has a high percentage of carbon, often between 20 and 40%.

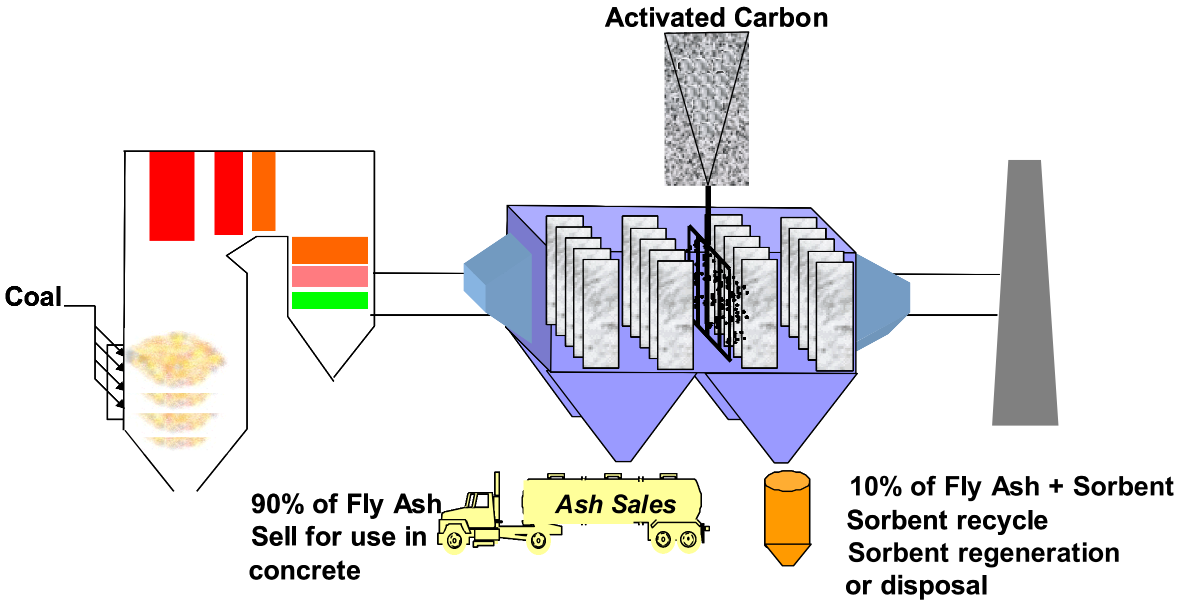

Figure 2. TOXECON II™ Configuration.

Overheating has not been discussed in any published information during tests with PAC in the first two configurations, where the ratio of carbon to ash is usually low. In five full-scale tests of TOXECON™ and TOXECON II™, overheating of PAC/ash in the hoppers occurred at two of these (Derenne 2006 and Martin 2007). Both of these sites also experienced plugged hoppers prior to overheating of the ash, and noted that they had difficulty emptying the PAC/ash mixture from the hoppers.

Interestingly, overheating was not reported during the yearlong test of carbon injection at Alabama Power's Plant Gaston. Testing was in the TOXECON™ configuration and the ash also had a high percentage of activated carbon; a similar carbon-to-ash ratio experienced at Presque Isle. A comparison of process and design parameters between Gaston and Presque Isle baghouses was compiled and is shown in Table 1. Several items stand out as potential significant differences between the two systems, including coal type, hopper evacuation schedules, and use of hopper heaters. Hopper heaters were also not used at the two TOXECON II™ sites, which did not report any flowability or overheating issues (DOE Quarterly Reports).

Table 1. Comparison of Presque Isle Power Plant and Plant Gaston Baghouse Designs.

	Plant Gaston	**Presque Isle Power Plant**
Manufacturer	Hamon Research-Cottrell	Wheelabrator Air Pollution Control
Type	Low-pressure pulse-jet	Medium-pressure pulse-jet
Configuration	Hot-side ESP/COHPAC®	Hot-side ESP/TOXECON™
Coal	Low-sulfur eastern bituminous	PRB
Design air-to-cloth (gross) ratio	8:5	5:5
Cleaning	On-line	On-line
Bag length (feet)	23	26
Bag diameter (inches)	4.9 equivalent (oval bag)	5.0
Bag material (nominal weight)	18 ounce/yd^2 PPS	18 ounce/yd^2 PPS
Pulse pressure (psi)	12	35
Ash loading (gr/acf)	0.03–0.14	0.0048
Outlet emissions (lb/MMacf)	0.0045	0.0066
Ash LOI (%)	11–25	<0.5
PAC type	NORIT DARCO® Hg	NORIT DARCO® Hg
PAC loading (lb/MMacf)	0.5–2.0	0.5–2.0
PAC loading (gr/acf)	0.0016–0.0128	0.0032–0.0128
Time of operation with PAC	8 months	~ 5 weeks
Hopper heaters	None	Yes, Thermon resistance heaters (12.5 kW/hopper)
Hopper evacuation schedule	Every 2–3 hours per B. Corina at Gaston. (When requested, operators would shut off ash pulling system to build up ash for a sample.)	Every 12 hours (prior to overheating event)
Fluidizing system	Vibrators	Vibrators
Ash system	Wet, hydroveyor	Dry, pneumatic
Overheating of hopper ash/PAC	No	Yes, all hoppers
Number of cage sections	2	2

CASE STUDY—PRESQUE ISLE TOXECON™ DEMONSTRATION

This project is being conducted under the Department of Energy's Clean Coal Power Initiative (CCPI). The project is taking place at the We Energies Presque Isle Power Plant (PIPP) located in Marquette, Michigan. The project features the installation and commercial demonstration of the EPRI-patented TOXECON™ air pollution control process. At Presque Isle, the existing particulate collectors are hot-side electrostatic precipitators.
After several weeks of parametric testing, hot, burning embers were found in one hopper while operators were working to unplug and evacuate it. This compartment was isolated and the baghouse remained in service. All of the compartments were then checked and embers were found in all of the hoppers. The compartments were isolated, PAC injection was discontinued, and the baghouse put into bypass mode. The hot PAC/ash in each hopper was cooled and removed.

Loss on ignition was measured on select ash samples and values ranged from 10 to 35%. The LOI in the ash entering the baghouse was less than 1%. Thermogravimetric tests performed on the PAC and PAC/ash mixture showed a heat of combustion of around 850ºF, although smoldering of the PAC occurred at around 780ºF.

An investigation of system operation and the ductwork showed no evidence that a burning substance had passed into the TOXECON™ baghouse and ignited the mixture.

Heaters are used on the hoppers in this baghouse and specifications showed that they could reach temperatures up to 800°F. At the time of the incident they were set to maintain an average temperature of 290°F. After all of the hoppers were emptied, thermocouples were placed on the hopper walls and the maximum wall temperature measured was about 430°F. It is suspected that hopper heaters caused localized high temperatures that increased the temperature of the accumulated PAC/ash mixture and, because of the insulating properties of the mixture, heat could not be dissipated.

DESCRIPTION OF CURRENT TESTING TO DETERMINE CAUSE OF ASH OVERHEATING

Several groups are conducting tests to determine the cause(s) of overheating of the ash mixture in the hoppers. Testing includes analysis of the PAC/ash mixture and PAC for ignition properties. Tests are also being conducted in laboratory mock-ups and in the hoppers at Presque Isle to recreate the conditions that caused the overheating.

All tests to date confirm that the ignition temperature of PAC or of the PAC/ash mixture is greater than 750°F.

Laboratory Testing of Frank-Kamenetskii Model
(DOE Quarterly Report No. 41766R10)

Literature searches revealed a model to predict auto-ignition of combustible materials called the Frank-Kamenetskii Model. This model predicts that spontaneous combustion can result from internal heating of a combustible solid if the solid is sufficiently porous to allow oxygen (air) to permeate it and if it produces heat faster than it can be liberated, which can happen with a highly insulating material. This phenomenon is normally associated with a relatively large mass of material (small surface-to-volume ratio). The model describes a relationship between the radius of a specimen and the self-ignition temperature in a defined geometry.

Laboratory oven tests were conducted on different size square containers filled with PAC/ash mixtures from the hoppers at PIPP. The containers were made from carbon steel, which is the material used in the hoppers. Thermocouples were placed in the oven and inserted into the center of the bed of material at different levels to track temperature profiles over time (Figure 3).

Figure 3. Laboratory Setup for Auto-Ignition Tests.

Temperature profiles from testing at 340°F and 430°F on a six-inch bed loaded with a PAC/ash material with an LOI of 26% are shown in Figure 4. These tests confirmed that at

430°F, sufficient heat was generated to increase the temperature of the mixture to ignition temperatures. The same test was performed using pure PAC and it showed a very similar ignition profile (Figure 5). (Even though the LOI was so much higher? 68.8%)

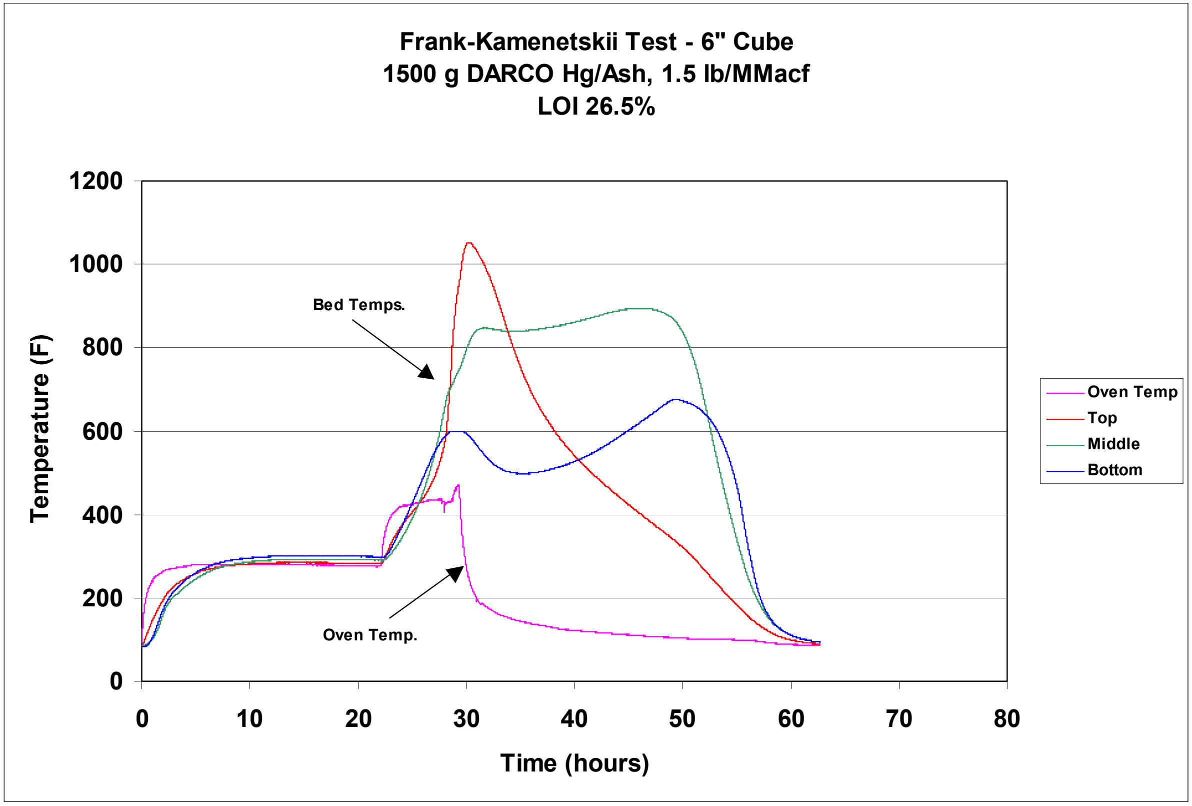

Figure 4. **Auto-Ignition Test on 26% LOI PAC/Ash from the Hoppers at Presque Isle.**

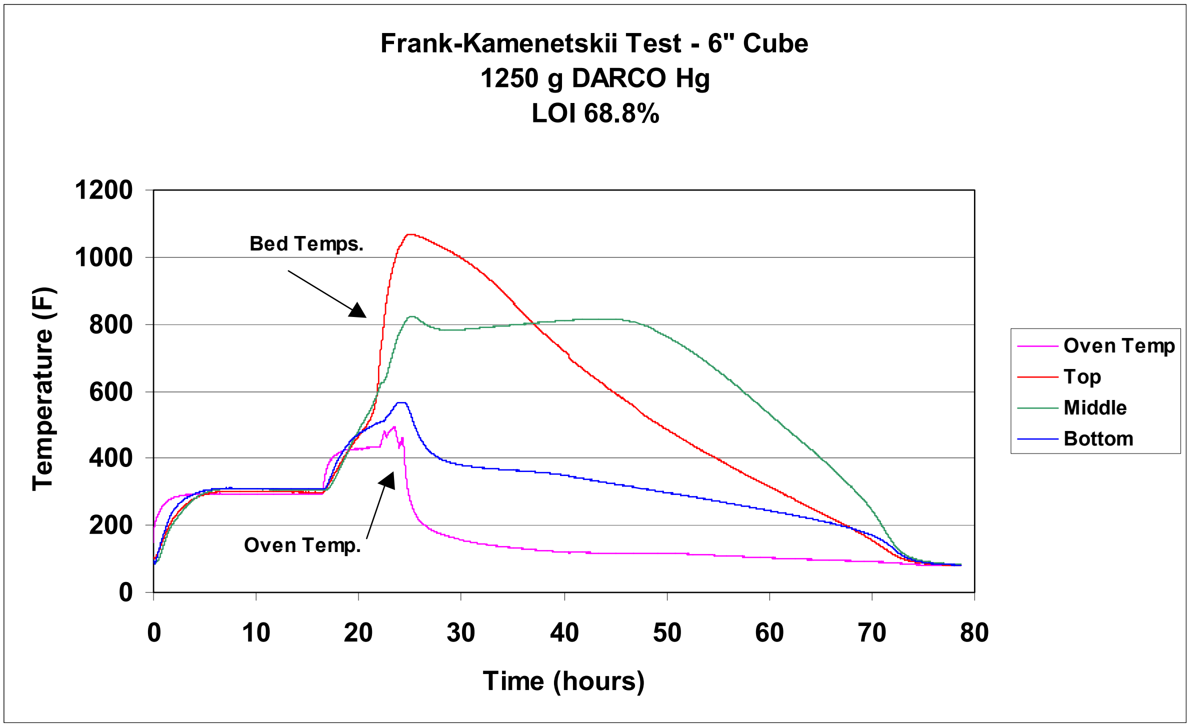

Figure 5. Auto-Ignition Test on DARCO® Hg PAC Only.

The same test was repeated using ash sampled from Presque Isle at lower injection concentrations and still using DARCO® Hg PAC. The LOI was measured at 7.8%. As seen in Figure 6, the sample overheated very little and did not auto-ignite at the same temperature as the higher LOI sample.

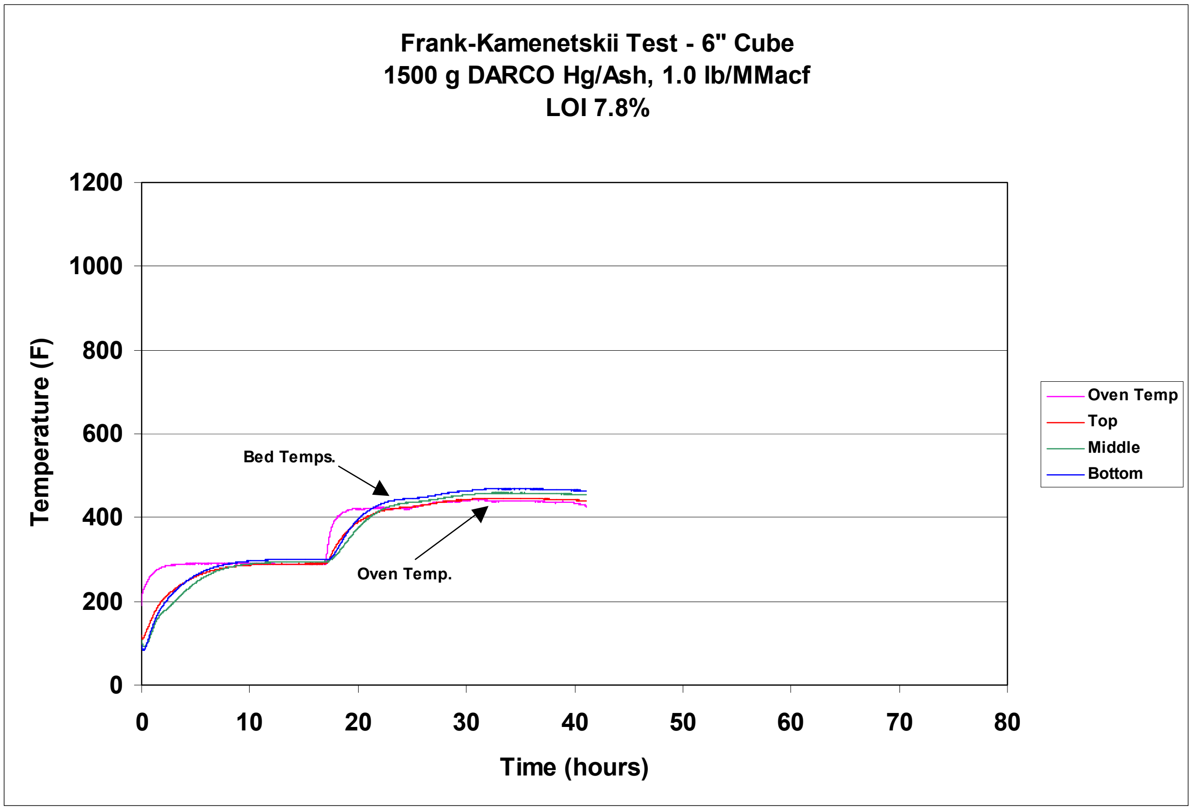

Figure 6. Auto-Ignition Test on 7.8% LOI PAC/Ash from the Hoppers at Presque Isle.

A test was performed on an ash sample from a site with a high natural ash LOI (Figure 7). Approximately 35% of the LOI in the sample was natural and the remainder was from PAC injection. The overall LOI of the sample was 41.6%, which should have resulted in auto-ignition, but the sample showed very little overheating and did not auto-ignite at the same conditions as the high LOI ash at Presque Isle. This test indicates that LOI alone is not an indicator of auto-ignition risk.

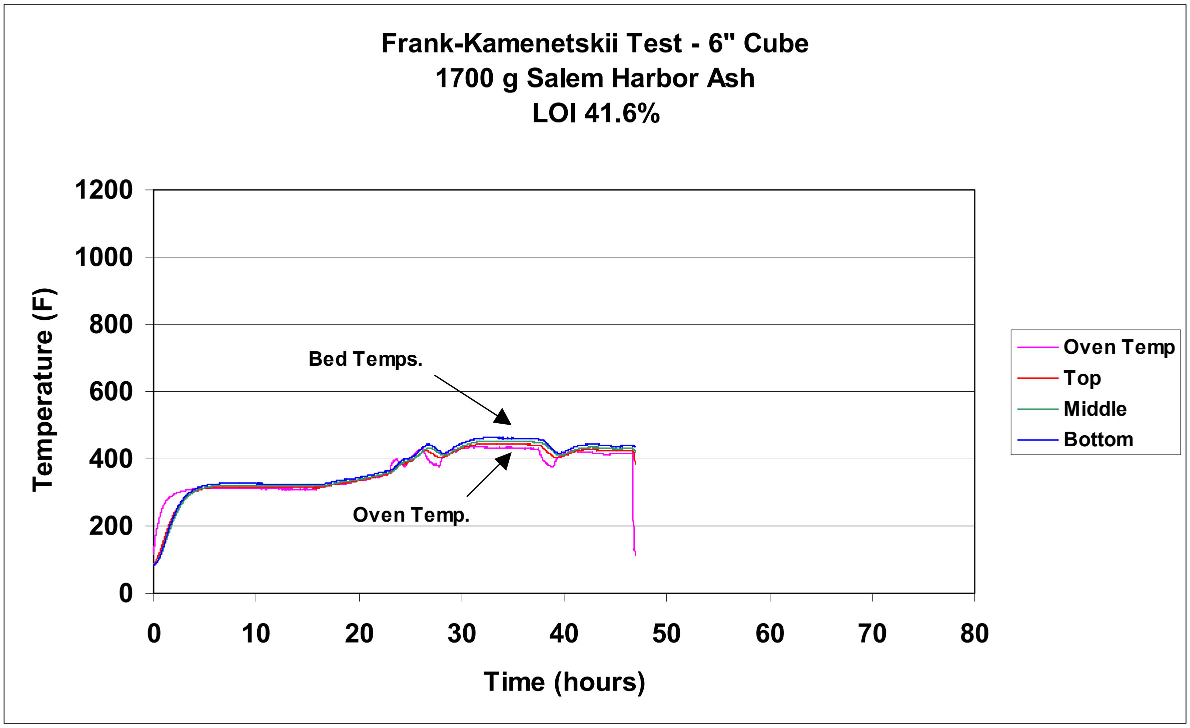

Figure 7. Auto-Ignition Test on 41.6% LOI PAC/Ash Sample.

The LOI was measured for various samples. Samples tested to date showed that PAC/ash mixtures with an LOI of 15% or lower did not ignite at the same conditions as those of 26% and higher. Further testing will be done to determine if there is a minimum LOI required for auto-ignition.

Tests are ongoing to determine the effect of the following on auto-ignition:

- LOI: Low LOI samples did not ignite at the same temperature as samples with a higher LOI percentage.
- Bed size: Smaller beds require higher temperatures to auto-ignite.
- Oxygen concentration: Will a lower oxygen environment in the flue gas reduce the amount of heat generated?
- Carbon type: High natural LOI does not seem to ignite at the same temperature as high surface area carbon.

INDUSTRY EXPERIENCE OPERATING WITH HIGH-CARBON SOLIDS

Hopper Evacuation Equipment

Following is a general overview of existing equipment used to aid in removal of solid material from hoppers. Emptying the hopper more frequently minimizes the temperature rise in the hopper and cools the carbon ash mixture—continuous removal is the best approach.

Acoustic Horns

GE Energy has reported that acoustic horns have worked and should be one of the correct applications for assisting hopper ash flowability as opposed to mechanical vibrators, which have the unintended consequence of potentially causing ash to solidify in the hoppers. Two reasons this solidification may happen are:

- The rough surface area common to fly ash and essential to activated carbon for mercury collection may form a loose crystalline structure when vibrated, caking the material on the sides of the hopper, and preventing proper discharge of the hopper material.
- ADA-ES has experience with heating PAC and PAC/ash mixtures in a laboratory environment. Mixtures with a high PAC content show an increased "stickiness" with increasing temperature, both in cohesiveness and adhesiveness to the walls of containers.

The effect of these conditions on the viability of vibrators as a fluidization source may not be as important to ESP operation as to baghouse operation. The ESP hopper operates after the application of an applied charge via the electrodes and collector plates of the ESP, potentially minimizing the charge differential between ash and carbon.

Fluidizing Air

Another viable option to acoustic horns is the use of fluidizing air to enhance hopper ash flow and prevent unintended hopper ash buildup. Fluidizing air works on the general principle of creating a bubble beneath the hopper ash, which breaks the physical bonds holding the ash-carbon mixture to the hopper walls and prevents settling of the collected material.

However, if sufficient material accumulates in the hopper "fluidized air in the hopper, whether it be intentional or a leak in the hopper or evacuation system can turn hot spots into fires reaching temperature of 2,000°F plus."

"A summary from Carleton University notes that spontaneous combustion can/will occur in the mass if oxygen/air is allowed to permeate the hopper." This should be taken into account when considering fluidizing air as the means to aid ash removal. This approach is not recommended.

Air Cannons

An air cannon, is de-clogging equipment composed of two main elements: a pressure vessel and a triggering mechanism. They are permanently installed on silos, bins, and hopper walls. Air cannons do not require any specific air supply. Available plant air is sufficient with a minimum of 60 psi, although 75–90 psi is preferred for better results. The average air consumption is moderate and depends on the number of firings per hour, size of the pressure vessel, and number of air cannons installed. The compressed air contained in a pressure vessel is instantly released, and the blast evacuates material sticking to the walls (rat holing), as well as breaking potential bridging due to the shockwave produced. The blasts are usually organized by using an automatic sequencer. There are typically two different versions of air cannons—a high-temperature version used mainly for heat exchanger and cooler applications to remove clogging and to avoid costly plant stoppages and downtime; and a low-temperature version used to eliminate buildup and dead stock of powdery and granular materials, thus preventing caking and enabling the optimization of storage capacity.

Air cannons also have the liability of introducing oxygen into the dust. This could result in igniting a hot spot.

Rappers

Rappers are used to mechanically dislodge collected particulate/materials within an electrostatic precipitator or fabric filter by rapping or impacting the hopper walls. They can be electronic or air driven. A rapper system is designed so that rapping intensity and frequency can be adjusted for varying operating conditions. Once the operating conditions are set, the system must be capable of maintaining rapping for long periods of time. Proper rapper design and timing will minimize dust reentrainment and prevent precipitator deterioration. There is a variety of rapper designs to choose from—collection plates are rapped using hammer/anvil or magnetic impulse systems. Ridge frame discharge electrodes are rapped by tumbling hammers, while wire discharge electrodes are rapped by vibrators.

The hammer/anvil system is a European design that uses hammers mounted on a rotating shaft. The hammers drop and strike the anvils that are attached to the collection plates. The intensity of the rapper is controlled by the weight of the hammer and the length of the hammer-mounted arm. Rapping frequency is controlled by adjusting the speed of the rotating shaft.

Electrostatic precipitator manufacturers in the U.S. favor the magnetic impulse design to remove particles from collection plates. The system has a steel plunger that is raised by a current pulse in a coil. The plunger is released by gravity and strikes a rod connected to a number of plates within the precipitator. An electrical control panel can regulate the frequency and intensity of the rapping system. Typically, magnetic impulse systems operate more frequently and with less intensity than rotating hammer/anvil rappers.

Electrostatic precipitators with rigid frame discharge electrodes are rapped with tumbling hammers. Tumbling hammers operate similarly to the hammer/anvil systems that remove particles from collection plates. In this design, the hammers are arranged horizontally on a shaft. As the shaft rotates, the hammers hit an impact beam that transfers the shock or vibration to the center tubes on the discharge system causing the particles to fall.

Wire discharge electrodes can also be rapped using air or electric vibrators, which gently vibrate the discharge wires. Vibrators are positioned externally on the precipitator roof and are connected by rods to the high-tension frames supporting the wire electrodes. This design has an insulator located above the rod, which electrically insulates the rapper while transmitting the rapping force mechanically.

One drawback of rappers is that they can further increase hopper pluggage if not controlled correctly or if there is a failure of the hopper airlock. Fly ash will pack if the rappers are operated and ash is prevented from flowing from the hopper. The rapper operation must be interlocked with the hopper airlock and conveying system operation.

Design Issues

Hopper Valve Design

Hoppers are equipped with manual or automatic discharge devices that allow the hopper contents to be emptied. Manual discharge devices include slide gates and hinged doors and drawers. Slide gates are held in place by a frame and sealed with a gasket. This device should not be used with carbon. Hinged doors and drawers are used only on very small units that operate on a periodic basis and are not recommended when evacuating carbon. Automatic continuous discharge devices include double dump valves and rotary air lock valves, and can be used to evacuate high-carbon ash. As ash collects in the hopper, the weight pushes down the counterweight of the top flap and the ash moves downward. As the top flap closes, the bottom flap opens and the ash falls out. Double dump valves are available in gravity operated and motorized versions. Rotary air lock valves employ a paddle wheel that forms an airtight seal with the hopper housing. A motor slowly moves the blades to allow the ash to discharge from the hopper. This design is typically used on medium- to large-sized ESPs and fabric filters. Hopper valves must be designed to both easily discharge fly ash from the hopper and to prevent air infiltration into the hopper. Experience has shown that a minimum 12 inch discharge valve will minimize packing or bridging at the hopper discharge throat.

Infiltration or air leakage into the hopper must be eliminated. First, it is a source of oxygen for the carbon combustion and second, it can lead to bridging above the hopper discharge.

Hopper Design

Hoppers are located at the bottom of precipitators and/or baghouses to collect and temporarily store dust and particulates removed during the rapping process. Hoppers are usually designed with a 55–60º valley angle from horizontal, since material first builds up in the hopper valley or corners to allow dust to flow freely from the top of the hopper into the bottom discharge opening.

Hopper designs typically feature devices that facilitate quick and efficient particulate discharge such as a strike plates, poke holes, vibrators, and rappers. Strike plates are welded to the lower third center of the hopper wall. If particle buildup occurs in the hopper, rapping the strike plate will dislodge the stuck material. Hopper designs also include access doors or ports that allow easier access for cleaning, inspection, and maintenance of the hopper. Hopper doors also need to be routinely inspected for air leakage. Hopper vibrators are periodically used to remove dust from the hopper walls. The vibrators cause the side walls of the hopper to vibrate, thereby removing built-up particles. Vibrator operation must be interlocked with hopper airlock operation to prevent packing as outlined above.

Hopper Heaters

The heating system must preheat the hopper to prevent moisture condensation and must maintain the fly ash at a sufficiently high temperature during normal operation to prevent fly ash cool-down, agglomeration, and plugging. The amount of heat applied to the hopper must be determined by the heater manufacturer. Lowering the temperature of the hopper to reduce the rate of oxidation of the carbon may minimize the risk of a carbon exotherm in a power plant application. Base losses are calculated by the manufacturer based on on-line temperatures, ambient temperatures, thermal insulation, etc. Also, allowance must be made for poke tubes, strike plates, vibrators, man-ways, etc., which are additional source of heat loss. Heater suppliers should give the end-user a heat loss calculation sheet based on historical successes. A key feature of a successful system is the watts density of the heaters. This is the amount of heat (watts) per unit area (square foot). Low-watt heating modules attach directly to the hopper to maintain temperature above dew point, preventing condensation and plugging. Hopper heaters need to be calibrated so that the surface temperature does not exceed 390ºF.

Some low sulfur coal applications have operated successfully without hopper heaters. If an installation has a low inlet ash loading, (e.g. TOXICON), dust level in the hopper can be maintained at a low level by frequent hopper evacuation; the ash, then, does not insulate the hopper wall fro the flue gas, and hopper heater operation may not be needed. Current operation at Presque Isle is to pull the ash every 2-4 hours and to use hopper heaters only for cold start-up.

Detection Options

CO Detectors

Carbon monoxide (CO) monitors have been used since the late 1960s as early warning indicators before the pre-ignition reaction has completely developed into a fire generated by spontaneous combustion. The installation of a CO monitor in a hopper would show a small increase in CO levels before ignition and large levels during ignition. However, these short-lived peaks could be caused by changes in the combustion process and other operational upsets. CO monitors cannot reliably predict a potential explosion that occurs prior to the onset of detectible fire condition levels.

Level Switches

Level switches are used to detect liquid or powder levels, or interfaces between liquids. These level measurements can be either continuous or point values represented with various output options. Continuous level switches are devices that measure level within a specified range and give output of a continuous reading of level. Point level switches mark a specific level generally used as high alarm or switch. Multiple point switches can be integrated to give a stepped version of continuous level. These level switches can be either plain sensor with some sort of electrical output or can be more sophisticated instruments that have displays and sometimes computer output options. The measuring range is probably the most important specification to examine when choosing a level switch. Field adjustability is a useful feature to have for tuning the instrument after installation.

Depending on the needs of the application, level switch devices can be mounted in different ways. These sensors can be mounted on the top, bottom, or side of the hopper. Among the technologies for measuring level are air bubbler technology, capacitive or RF admittance, differential pressure, electrical conductivity or resistivity, mechanical or magnetic floats, optical units, pressure membrane, radar or microwave, radio frequency, rotation paddle, ultrasonic or sonic, and vibration or tuning fork technology. Analog output level sensors can be current or voltage signals. Also possible is a pulse or frequency. Another option is to have an alarm output or a change in state of switches. Computer signal outputs that are possible are usually serial or parallel. Level switches can have analog, digital, or video displays. Controls for the devices can be analog with switches, dials, and potentiometers; digital with menus, keypads, and buttons; or controlled by a computer. Level switches have been historically used to alarm a full hopper or a plugged discharge. Capacitance probes or nuclear devices have been used. The nuclear design uses an external source and detector. It is not affected by buildup on an internal sensor.

The height of the level switches in a hopper is normally set at either a point to minimize ash re-entrainment back into the flue gas in and ESP or a FF. The installation level can be lower or a second indicator added for a high carbon ash to alarm a possible ash heat up condition.

O&M Procedures

The following are several operational and maintenance considerations to minimize the occurrence of thermal events in a power plant with a TOXECON™ configuration. PAC/ash mixture can ignite with sufficient time and quantities at temperatures above 400ºF. Operators must consider minimizing PAC/ash storage in baghouse hoppers by evacuating the hoppers continuously, thereby preventing material buildup. The control of hopper temperatures by minimizing the use of hopper heaters is another operational consideration. The installation of additional thermocouples in the lower hopper assists in the early detetion of thermal events. WE Energies is currently testing the ability of a CO monitor to provide early detection of a hot spot.

SUGGESTIONS FOR OPERATION WITH HIGH-CARBON SOLIDS

Working with industry, the following, preliminary design considerations and procedures are recommended to minimize the risk overheating of high-carbon ash in hoppers:

1. Eliminate the use of hoppers heaters.
2. If using hopper heaters, change the hopper heater control from an on-off mode to a more tightly constrained temperature band. This should result in a lower peak temperature output of the heater. Also, consider using hopper heaters only during start-up and shutdown.

3. Add or increase temperature monitoring in the hopper to include temperature sensors inside the hopper. This will help with early indication of unusual temperature increases. Thermocouple placement is important.
4. Consider hopper design issues to ensure proper flowability of the collected material, especially with a high PAC-to-ash ratio.
5. Select a means of fluidization other than vibrators that does not promote packing of the material. Options that are currently in operating systems throughout the utility industry and other industrial sites are fluidization using gas (air) or sonic horns. Further testing should be conducted to determine the effectiveness of vibrators for TOXECON™ systems.
6. Employ a hopper evacuation schedule that frequently removes hopper materials from the hoppers, preventing material buildup.
7. Install a hopper level detector system and ensure its reliable operation. The level detector should be at a low enough level to indicate inappropriate buildup of material.
8. When working around PAC, any operations that produce heat such as welding, cutting, etc., should occur only after all PAC has been removed from the work area. Even a small piece of hot metal or other hot material dropped into PAC will eventually cause ignition of the material, even at ambient conditions and without another heat source.

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