TOXECON™ CLEAN COAL DEMONSTRATION FOR MERCURY AND MULTI-POLLUTANT CONTROL AT THE PRESQUE ISLE POWER PLANT

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ABSTRACT

We Energies and DOE, under a Clean Coal Power Initiative program, are working together to design, install, evaluate, and demonstrate the EPRI-patented TOXECON™ air pollution control process as an integrated emissions control system for mercury and particulate matter from three 90-MW units at the Presque Isle Power Plant located in Marquette, Michigan.

The process involves the injection of activated carbon between the existing particulate collector and a fabric filter installed downstream. The sorbent collects mercury that is then removed from the flue gas using the baghouse. The project has also recently investigated SO_2 and NO_x control using sorbent injection. Demonstration of TOXECON™ began in February 2006 and is scheduled to continue through early 2009. This paper will discuss balance-of-plant issues encountered during startup in 2006 as well as ongoing issues. Mercury removal results from optimization and long-term testing will be presented as well as current efforts in SO_2 and NO_x trim control.

INTRODUCTION

The Department of Energy's Clean Coal Power Initiative (CCPI) is an industry/government cost-shared partnership to implement clean coal technology under the National Energy Policy. The National Energy Policy investment in clean coal technology focuses on increasing the domestic energy supply, protecting the environment, ensuring a comprehensive energy delivery system, and enhancing national energy security. CCPI is an important platform for responding to these priorities. The CCPI was initiated in 2002 with a goal of accelerating commercial deployment of advanced technologies to ensure the United States has clean, reliable, and affordable electricity.

We Energies has over 3,200 MW of coal-fired generating capacity and supports an integrated multi-emission control strategy for SO_2, NO_x, and mercury emissions while maintaining a varied fuel mix for electric supply. The primary goal of this project is to reduce mercury emissions from three 90-MW units that burn Powder River Basin coal at the We Energies Presque Isle Power Plant. Additional goals are to reduce nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter (PM) emissions, allow for reuse and sale of fly ash, demonstrate a reliable mercury continuous emission monitor (CEM) suitable for use in the power plant environment, and demonstrate a process to recover mercury captured in the sorbent. To achieve these goals, We Energies has designed, installed, and is operating a TOXECON™ system designed to clean the combined flue gases of Units 7, 8, and 9 at the Presque Isle Power Plant.

TOXECON™ is a patented process in which a fabric filter system (baghouse) installed downstream of an existing particle control device is used in conjunction with sorbent injection for removal of pollutants from combustion flue gas. For this project, the flue gas emissions are controlled from the three units using a single baghouse. Mercury is controlled by injection of activated carbon or other novel sorbents, while NO_x and SO_2 will be controlled by injection of sodium-based or other novel sorbents. Addition of the TOXECON™ baghouse also provides enhanced particulate control. Sorbents are injected downstream of the existing particle collection device to allow for continued sale and reuse of captured fly ash, uncontaminated by activated carbon or other sorbents.

The project team includes We Energies, ADA-ES, Inc., DOE-NETL, Cummins & Barnard, and EPRI. We Energies is providing and operating the demonstration site, as well as project management, environmental permitting, and reporting. ADA-ES is the project management interface with NETL, and is responsible for reporting, design of the mercury control system, design of the mercury monitoring system, and demonstration testing of the entire process. Cummins & Barnard provided architect and engineering services, construction management, design and specification of equipment, equipment installation, and startup training for plant operators. EPRI provides technical advice to We Energies.

PROJECT DESCRIPTION

The project is taking place at We Energies' Presque Isle Power Plant (PIPP) located in Marquette, Michigan. This project was applied to Units 7, 8, and 9, each of which is a 90-MW unit with an individual hot-side electrostatic precipitator (HESP) as the primary particulate matter (PM) control device. The exhausts from the three HESPs were originally ducted into individual flues of a common stack. The project involves controlling the emissions from the three units using a single baghouse. Integrating the three units into one project and structure provides cost savings over treating the units separately, and optimizes the use of space.

The TOXECON™ process is ideal for Presque Isle because the existing HESP exhausts benefit from the additional PM control, especially during startup and shutdown. Also, the existing HESPs used for PM control do not have the ability to remove mercury from the flue gas, and injection of powdered activated carbon (PAC) into these HESPs is not feasible due to the high flue gas temperatures. The TOXECON™ process also allows We Energies to continue to sell its fly ash from the HESPs because the carbon is injected downstream of these units.

The Powder River Basin subbituminous coal used in Units 7–9 is supplied by several mines in Wyoming and Montana (dependent on the price of the fuel) and shipped by rail to Superior, Wisconsin, where it is then loaded onto a lake boat for delivery to the PIPP.

The main challenge in applying the TOXECON™ process at PIPP was to combine the flue gas streams from three independent Units into one combined stream and then separate the streams after the baghouse and connect to the three separate flues in the existing chimney. The process layout is shown in Figure 1. From a Mechanical and Process standpoint, the combined flue gas flow is not unitized. However, the Electrical and Control Systems were installed primarily on a Unit basis. The design of these systems was done to minimize the possibility of a single generation Unit failure from tripping the remaining two units. A design philosophy of "no single Unit trip should trip the remaining two Units" was repeated throughout the design phase of the project.

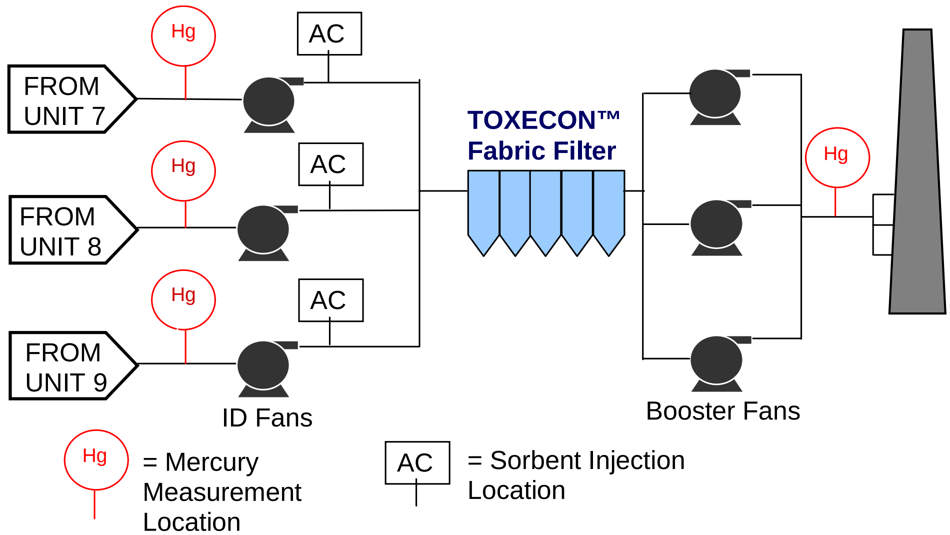

Fig. 1. Basic schematic of PIPP TOXECON™ process.

A pulse jet style baghouse was selected for Presque Isle. This style reflects a typical industry standard and requires a small footprint area for the congested Presque Isle site. Based on a competitive bid process, a baghouse provided by Wheelabrator Air Pollution Control was selected. The baghouse is appropriate for the Presque Isle TOXECON™ project since baghouses of this type have been installed successfully in other power plant applications where the flue gas flow and particulate loading were much higher than the conditions at Presque Isle.

Project Goals

The specific goals of this project are:

- Achieve 90% mercury removal from flue gas through activated carbon injection
- Demonstrate a reliable, accurate mercury CEM suitable for use in the power plant environment
- Successfully integrate and optimize TOXECON™ system operation for mercury control
- Evaluate the potential for 70% SO_2 control and trim control of NO_x from flue gas through sodium-based or other novel sorbent injection
- Reduce PM emission through collection by the TOXECON™ baghouse
- Recover 90% of the mercury captured in the sorbent
- Utilize 100% of fly ash collected in the existing electrostatic precipitator

Actual demonstration of the TOXECON™ technology began when flue gas from the first boiler was first introduced into the new TOXECON™ baghouse in December 2005. On January 27, 2006, all three Units were in service and at that time ADA-ES began commissioning the PAC injection system to begin the technology demonstration phase of the project.

RESULTS

Baseline Tests

TOXECON™ testing officially began after all three units were tied into the baghouse. Baseline tests were performed during the week of February 13, 2006. Baseline testing was done without PAC injection. Efforts included sampling of coal and ash, monitoring the CEMs and plant data, and performing mercury, halogen, and particulate testing on the flue gas into and out of the baghouse.

For particulates, a total of 24 test points were sampled using six ports at the baghouse common inlet and outlet test locations. The particulate sample trains met all specifications required by Method 5, 40CFR60. The baghouse particulate removal was 99.6% during baseline.

For mercury, a total of 24 test points were sampled using six ports at the baghouse common inlet and outlet test locations. The speciated mercury sample trains met all specifications required by the Ontario Hydro method. Table 1 shows a comparison of the average inlet and outlet measurements from 10 a.m. through 4 p.m. using the Thermo CEM and the Ontario Hydro Method. There was a 0.6% difference between inlet and outlet based on the CEM, but 9% when using the Ontario Hydro Method. The CEM and the Ontario Hydro results differed by 12% and 4.6%, which was well within the 20% agreement required by EPA to pass the Relative Accuracy Test Audit (RATA) for mercury.

Table 1. Comparison of Thermo CEM and Ontario Hydro Data.

Test Method	Inlet Average ($\mu g/sm^3$)	Outlet Average ($\mu g/sm^3$)	Differential (%)
Thermo CEM	4.99	4.96	**0.6%**
Ontario Hydro	5.67	5.20	**9.0%**
Differential (CEM & O-H)	**12%**	**4.6%**	

Based on the Ontario Hydro data, the elemental mercury at the inlet was 91% of the total and oxidized was the balance, with just a trace of the mercury particle-bound. At the outlet, the elemental portion was 88%, with the remainder in the oxidized form.

Baseline Performance Data

Figure 2 shows inlet and outlet mercury concentrations, flange-to-flange (fl-fl) pressure drop and inlet temperature. There was some drift on the outlet CEM because the calibration routine was not programmed properly. When this was corrected and the instrument began undergoing daily calibrations, the mercury levels returned to the expected values.

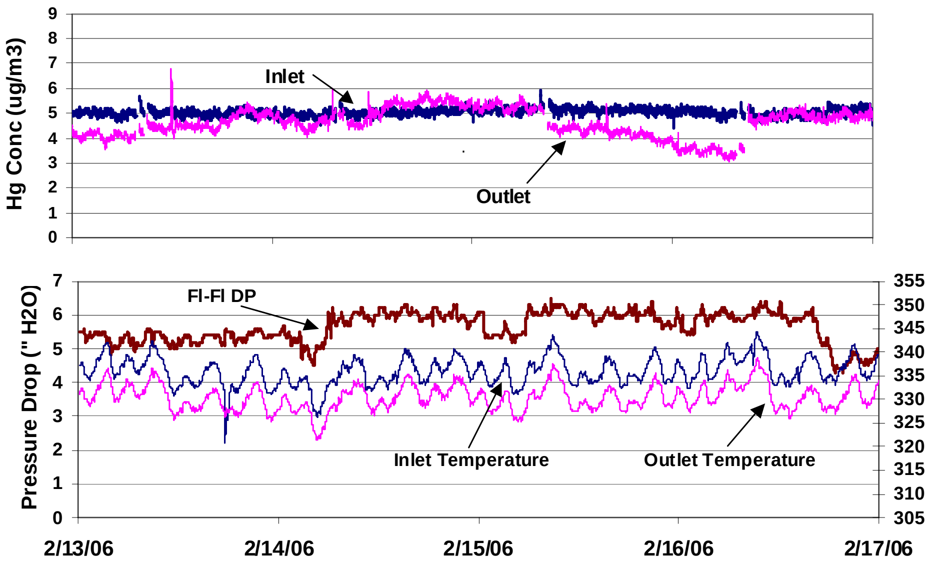

Fig. 2. Inlet and outlet mercury concentrations and baghouse pressure and temperature, February 13–February 17, 2006.

Parametric Testing

The overall goal of these tests was to establish a correlation between injection of a standard PAC, NORIT Americas DARCO® Hg, and halogenated PAC, DARCO® Hg-LH and mercury removal. Secondary goals included understanding the variables that impact mercury removal performance and to document any changes in baghouse performance. To minimize variables, it was decided to operate the baghouse at a pressure drop of nominally 6 inches W.C. and use a cleaning logic that was similar to baseline testing.

Parametric Performance Data

PAC injection was started on February 20, 2006, using DARCO® Hg. During the following months, several balance-of-plant issues interrupted the parametric tests (discussion below). Parametric testing using both DARCO® Hg and Hg LH was completed in December 2006.

The graph in Figure 3 summarizes the results of the parametric testing for the two sorbents tested; NORIT DARCO® Hg and Hg-LH. The data is limited to test results at flue gas inlet temperature of 330°F and baghouse cleaning set point of 6.5 inches W.C.

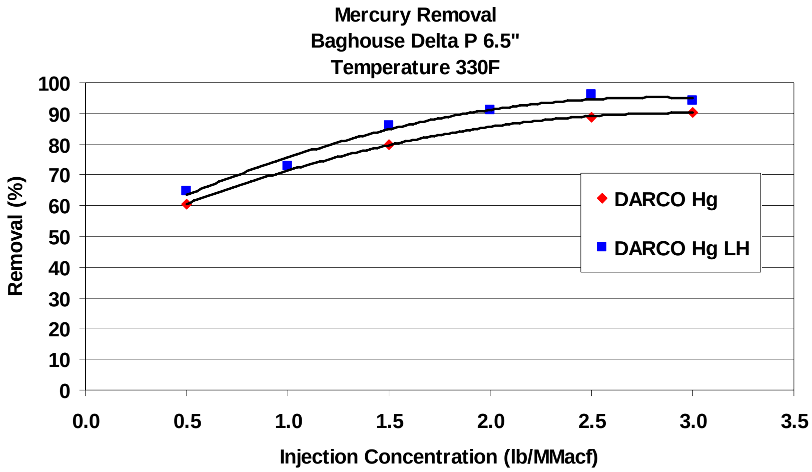

Fig. 3. Parametric Test Results—330ºF.

Figure 4 summarizes the results for all temperatures. This shows that DARCO® Hg at the lower injection concentrations was more affected by temperature than DARCO® Hg LH.

During the fourth quarter of 2006, tests were performed to determine the effect of reducing baghouse cleaning set point differential pressure (ΔP) on mercury removal efficiency. Up to this time, all of the testing had been with a set point of 6.5 inches W.C. When fl-fl ΔP reached 6.5 inches, cleaning of the baghouse would commence until the ΔP was reduced to 6.0 inches. For this testing, the set point was reduced by increments of 0.5 inches down to 5.0 inches. At each set point, data was taken for 2 days.

The data showed that at lower flue gas temperatures (< 320ºF) there was little difference in mercury removal between the four set points. At higher temperatures, mercury removal was significantly affected by pressure drop settings. In Figure 5, the effect of flue gas temperature on mercury removal efficiency is shown.

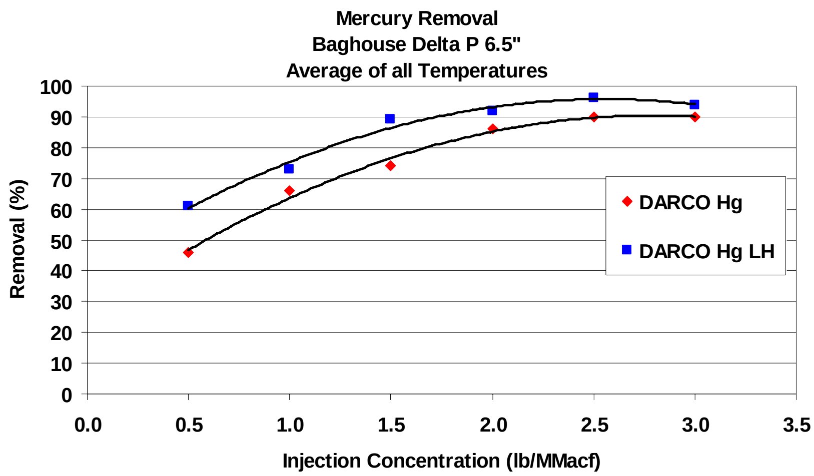

Fig. 4. Parametric test results—all temperatures.

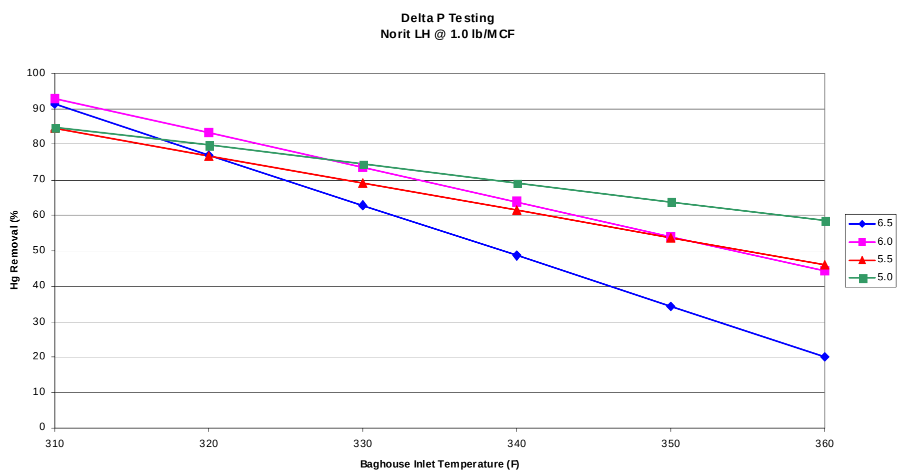

Fig. 5. Effect of baghouse pressure drop on mercury removal for 1.0 lb/MMacf DARCO® Hg LH.

The results of these tests indicated there is an advantage of running with reduced baghouse cleaning set point. Mercury removal was improved at higher inlet temperatures and fan power requirements were reduced. A significant increase in cleaning frequency did not become evident until the set point was reduced below 5.5 inches.

The pressure drop across the baghouse was then reduced from 6.5 to 5.0 in 0.5-inch increments at 1.0 and 1.5 lb/MMacf using DARCO® Hg LH sorbent at varying injection concentrations. At 2.0 and 2.5 lb/MMacf, tests were conducted at 6.5 and 6.0 inches only, since the effect of pressure drop was less noticeable at higher injection concentrations. Figure 6 shows the data for these tests. The removal efficiency is an average during the specific pressure setting and when temperatures were somewhat steady.

Long-Term Mercury Control Results

A significant milestone was met on January 19, 2007. The mercury removal was above 90% for 48 consecutive days (1152 hours), and We Energies determined that this was a sufficient time period to prove that the technology was capable of the targeted removal. During this time, both the DARCO® Hg and Hg-LH were being used, so both showed the capability of removing mercury at a high level. Further, thousands of additional hours have accumulated using PAC injection during normal operation and during parametric testing.

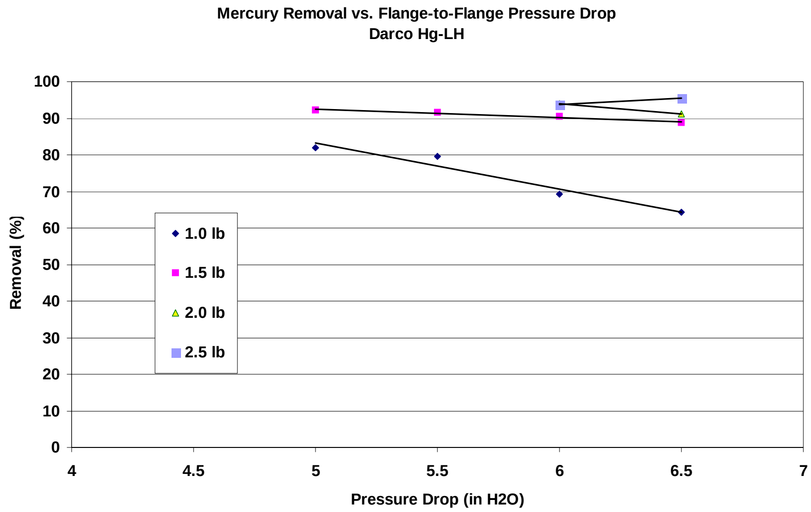

Fig. 6. Effect of pressure drop on mercury removal.

Effect of Air-to-Cloth Ratio

To determine the effect of air-to-cloth (AC) ratio on mercury removal, two time periods were chosen having constant PAC injection rate, flue gas temperature, flue gas flow rate, boiler load, and baghouse pressure drop. The only variable was the AC ratio. Figure 7 clearly shows that the mercury removal was not noticeably affected by the AC ratio at these conditions.

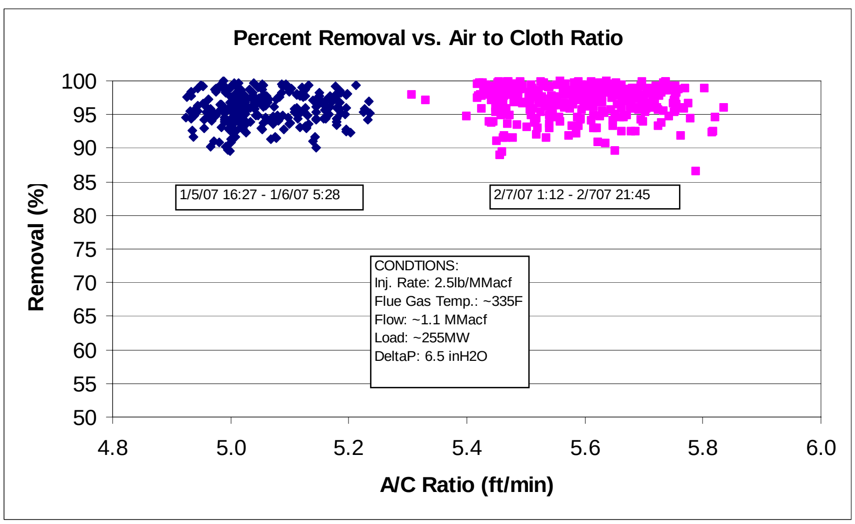

Fig. 7. Effect of AC ratio on mercury removal.

Mercury Loading on PAC/Ash Mixtures

Samples of PAC/ash mixture from the baghouse were analyzed for mercury content and Loss on Ignition (LOI). The ash at Presque Isle has a measured LOI of less than 1%, so the LOI in the PAC/ash mixture is primarily due to the PAC. Figure 8 shows the mercury loading in the mixture during several injection periods in 2006 and 2007. The mercury loading increased as the LOI (PAC fraction) increased, which is expected. The loading stabilized around 30–60 ppm except for the DARCO® Hg LH samples from June 2007. These samples showed a higher mercury loading than ones from the previous year. This may be due to improved baghouse operation.

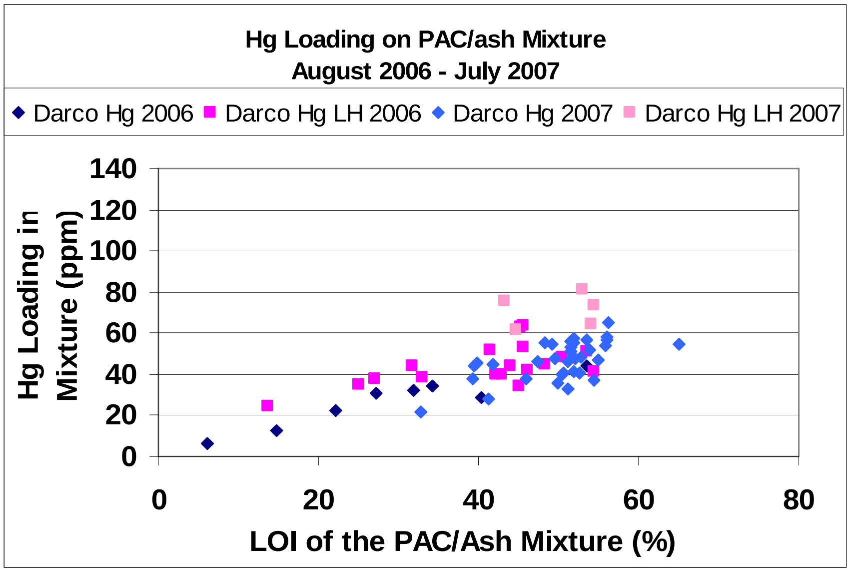

Fig. 8. Mercury loading on the PAC/ash mixture.

Drag Testing – Compartment 8

During the baghouse outage in February 2007, compartment 8 was opened and the test bags previously installed were inspected and drag measurements made. This compartment has OEM bags as well as experimental bags installed. The OEM bags in use are PPS fabric bags with the following specifications:

- Felted, 2.7-denier PPS fabric
- Weight of nominally 18 ounces/yd^2
- Singed on both sides
- Scrim material made from 3 ounces/yd^2 of PPS
- Mullen burst minimum of 500 psi
- Permeability at 0.5 inches H_2O of 25–40 cfm/ft^2

Table 2 presents the array of other bag materials installed for testing. In the case of the Kermel fabric, five swatches approximately 4" x 11" were installed in the compartment above the bags and pulse pipes. The swatches were exposed to flue gas and periodically one could be removed for strength tests. Although full-scale bags were preferred for the tests, using swatches reduced the risk of premature failures with experimental bags. For comparison, five OEM swatches were also installed.

Drag is a critical parameter in evaluating the performance of a fabric filter. Drag normalizes pressure drop to flow by dividing the average tubesheet pressure drop by the air-to-cloth ratio. The drag of eighty bags was measured in the compartment and eight bags were removed for weighing and laboratory testing—one each of the seven different types of test bags and one OEM bag. In addition, two swatches were removed.

During the inspection, there was obvious discoloration above rows G, H, and I in the area where three types of test bags were installed. The bags in these rows were all high-perm bags, types 9054, 9055, and 9056. The rest of the tubesheet looked clean.

This set of drag measurements was the first opportunity to quantify the filterability of the bags in a TOXECON™ baghouse after a period of operation. The bags were cleaned prior to taking the compartment off line, so these measurements should represent the residual drag of the dustcake formed in this application at this site. A listing of the bag type, drag measurement, and operating hours is shown in Table 3.

Table 2. Test Bag Materials.

Bag ID	Material/Design	Benefit	Quantity
9054	7-denier Torcon with 2.0 oz. PTFE scrim	High-perm fabric with more robust scrim	8
9055	7-denier Torcon with 4.0 oz. PTFE scrim	High-perm fabric with more robust scrim	8
9056	7-denier Torcon with Torcon scrim	High-permeability fabric	12
9065	Dual density Torcon (0.9- and 2-denier blend on filter side, 7-denier on other side)	High-perm on one side, high collection efficiency on other side	10
1342	P84	Higher temperature, higher collection efficiency	13
BHA-TEX	Scrim-supported PPS felt with a BHA-TEX expanded microporous PTFE membrane	Membrane provides higher collection efficiency and promotes light dustcake formation	12
Toray	Proprietary material		4
Kermel	Proprietary material		Swatches

Table 3. Drag Measurements and Bag Weights, 2/26/07 Drag Unit = inches H_2O/ft/min.

Bag Type	Average Drag 2/26/07	Estimated Operating Hours 2/26/07
2.7-denier Torcon (OEM)	0.25	8089
2.7-denier Torcon (OEM)	0.05	0
9054—high-perm	0.25	8089
9055—high-perm	0.24	8089
9056—high-perm	0.22	8089
9065—dual density	0.19	8089
1342—P84	0.25	8089
GE Energy—membrane	0.32	8089
Toray—proprietary	0.16	8089

Balance-of-Plant Issues

Overheating of PAC/Ash in Baghouse Hoppers

In early March 2006, after several weeks of parametric testing, hot, glowing 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.

Thermogravimetric tests performed on the PAC and PAC/ash mixture showed an ignition temperature of around 850ºF although smoldering of the PAC occurred at around 780ºF. 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 at the original setting was 407°F.

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 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 relation among the radius of a specimen, time, 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. Thermocouples were placed in the oven and inserted into the bed of material at different levels to track temperature profiles over time. These tests confirmed that at 430°F, sufficient heat was generated to increase the temperature of the mixture to ignition temperatures. The model predicts that larger bed sizes of the same material would auto-ignite at temperatures lower than 430°F.

When the critical temperature and bed dimensions are used in the model calculations, the result should be a linear correlation. Figure 9 shows the results from the tests using DARCO® Hg PAC and a mixture of PAC and ash with an LOI of 37%. As expected, the temperatures required to ignite the lower-LOI PAC/ash mixture are higher than for pure PAC.

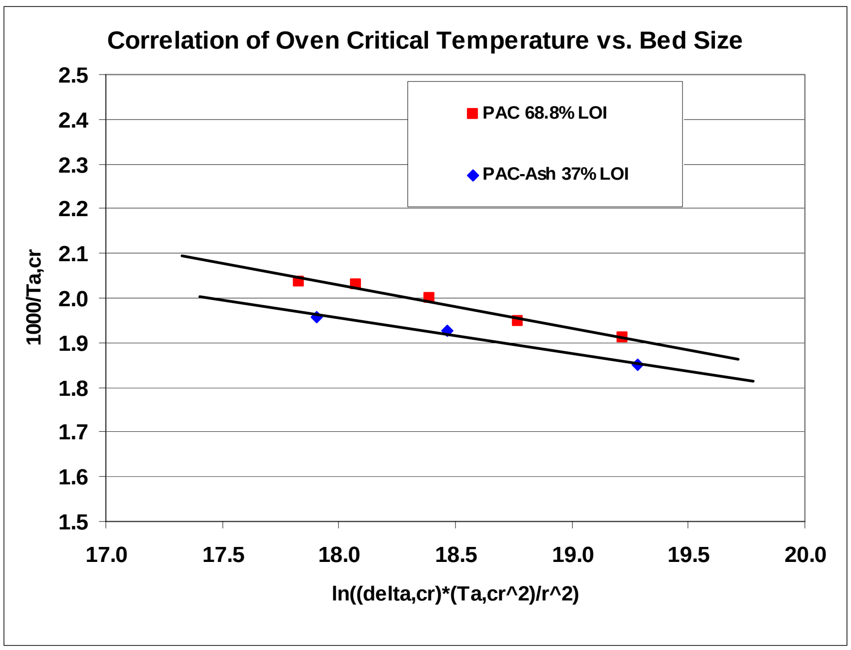

Fig. 9. Auto-ignition correlation using DARCO® Hg PAC.

A carbon monoxide monitor was used during several tests to determine if enough carbon monoxide is evolved to effectively use this as a method of detecting incipient combustion. During a test where the bed did not ignite but overheated significantly, approximately 40 ppm of carbon monoxide was produced. Figure 10 shows the carbon monoxide produced during auto-ignition. The monitor was set at a maximum concentration of 400 ppm. This level was exceeded during this test and peaked at the onset of ignition. These tests indicate that the use of carbon monoxide monitors may be useful for determining incipient combustion of PAC in hoppers.

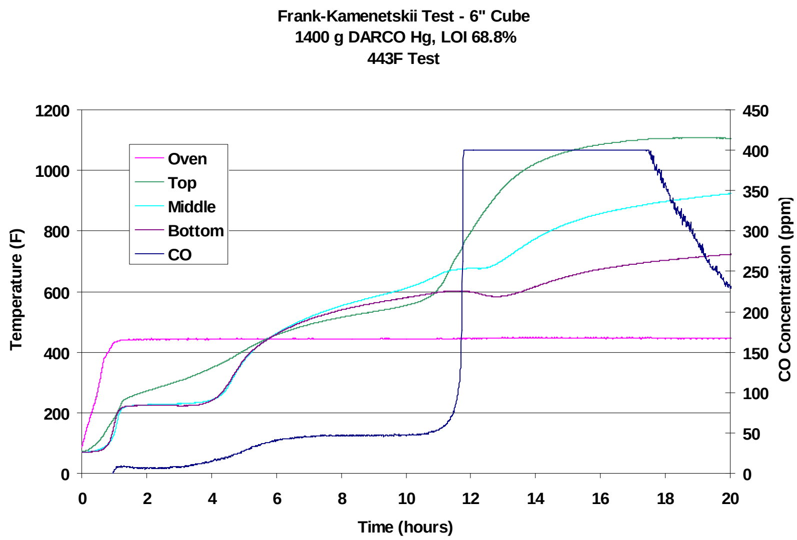

Fig. 10. Carbon monoxide produced during auto-ignition of PAC.

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

1. Eliminate the use of hoppers heaters.
2. If using hoppers 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 startup 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.
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. Current options that are in operating systems throughout the utility industry and other industrial sites are fluidization using a 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.

Fly Ash/PAC Dusting Problem

Because of the nature of the TOXECON™ installation at PIPP being a test activity, it was known that the ratio of fly ash to PAC in the baghouse hoppers would be highly variable. It was possible that the extremes of the two components would be possible, 100% PAC or 100% fly ash, or any mixture in between. It was also not possible to look to industry to see how other installations had selected their ash handling system for this type of application, since PIPP was really the first installation of this nature to attempt to handle this waste stream. An initial concern of the design team was not with conveying PAC/ash to the storage silo, but with unloading the silo to trucks for disposal.

United Conveyor Corporation (UCC), the supplier of the system, provided equipment that was proven to be successful handling normal power plant ash. A wet unloading system was selected to condition the ash/PAC mixture leaving the storage silo with water, thereby binding the dust to allow transportation by open bed trucks. During the initial days of PAC injection, there were difficulties with unloading the PAC/ash mixture due to uneven flow from the storage silo to the wet unloader. Modifications to the initial control system settings were made along with hardware modifications to provide more fluidizing air to the silo bottom and discharge control valve to help even out the flow variances. These modifications improved the unloading situation but still did not provide dustless operation.

UCC next provided modifications including adding air cannons to the bottom of the silo, increasing the size of the water spray nozzles, modifying the fluidizing control valve, and making additional control logic changes. These changes corrected the uneven flow problem but still resulted in excessive dusting when dumping into the open bed truck. Further modifications were tried including adding a flexible chute, internal baffles to the mixer, and adding a surfactant to the water sprays. Again there was improvement but not to the point were acceptable dustless operation was achieved.

At the end of third quarter 2006, there were still problems with excessive dusting during unloading of the ash silo using the wet unloader. The primary issue was controlling the flow of PAC/ash into the pin mixer. The diffuser valve was designed to meter PAC/ash from the silo into the pin mixer, where it was then sprayed with water. The PAC/ash mixture would bridge across the opening in the valve, resulting in limited flow into the mixer. When the valve would be opened further to reestablish flow, the PAC/ash mixture would break loose and overwhelm the ability to control dusting.

UCC conducted extensive pilot-scale testing using PAC. They reported successfully generating a dust-free product in their test lab. They indicated that a redesign of the wet unloader based on their test results should effectively solve the ongoing material handling issue. The redesign included a new mixer cover, raising the spray nozzles, dividing the mixer into three compartments, increasing the mixer speed, and adding a stop to the diffusion valve. The modifications to the wet unloader were completed in early October and tested. The results of these tests still showed uneven feeding of the PAC/ash mixture into the pin mixer.

UCC replaced the diffuser valve with a rotary valve. The silo was then unloaded using the wet unloader and there were minimal dusting issues. The ash flow into the mixer was controlled very well, and chemical surfactant was not needed even though it had been required previously to control fugitive dust. At the present time there are still occurrences of excessive dusting, primarily when starting the unloading process. UCC is proposing the addition of fogging nozzles to handle the fine particles that escape the mixer.

CONCLUSIONS

In collaboration with DOE in a Clean Coal Program, We Energies and team members successfully completed the design, construction, installation, and startup of the first commercial mercury control system, EPRI's TOXECON™ process, on a coal-fired utility power plant. The new air pollution control system became commercially operational in late January 2006.

Parametric results with PAC injection indicated the mercury removal efficiencies were at the project stated goals of 90% mercury removal rates.

After several weeks of continued PAC injection, balance-of-plant issues related to high carbon ash burning in the hoppers forced a delay in the testing. There have also been issues with the ash silo and wet mixing of the PAC/ash mixture from the baghouse. These balance-of-plant issues are exactly why DOE and industry team together to demonstrate new technologies. These alliances reduce financial and reliability risks to industry, while supporting the advancement of innovative, cost-effective new technologies. Working with industry, We Energies, DOE, and team members have identified the cause of burning PAC/ash in the hoppers, have developed preliminary guidelines for the safe operation of hoppers with high carbon ash, and continue to evaluate and gain experience in the operation of a TOXECON™ system. Long-term testing will continue through the middle of 2007. Additional testing to evaluate fabric filters, Trona injection testing for NO_x and SO_2 control, as well as ash management will continue until March 2009.