Commercial Operating Experience on an Activated Carbon Injection System

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ABSTRACT

One of the first commercial installations of an activated carbon injection (ACI) system was started up and tested at the Wisconsin Power and Light (WP&L) Edgewater Generating Station in the first quarter of 2008. Edgewater Unit 5 is a 380-MW plant that fires Powder River Basin (PRB) coal and is configured with a cold-side ESP for particulate control. The ACI system at Edgewater is configured to inject either upstream or downstream of the air preheater (APH). The initial testing was performed to determine the mercury removal capability versus carbon injection concentration. Two different powdered activated carbon (PAC) types were evaluated, including brominated PAC and PAC designed to be used with ash in concrete applications. Future sorbent enhancement tests are under consideration. Analysis of the balance-of-plant impacts including particulate emissions and opacity, and preliminary O&M costs, were evaluated, along with effects of PAC injection on fly ash utilization. This paper covers mercury control performance and operational impacts observed during initial commercial operation.

INTRODUCTION

The power industry in the U.S. is faced with meeting new regulations to reduce the emissions of mercury compounds from coal-fired plants. For many plants, activated carbon injection will be the simplest, most mature, and least expensive mercury control technology available. The DOE and industry have supported extensive Phase I, II, and III testing to fully understand the potential of activated carbon injection (ACI) for different plant configurations and operating conditions.[1-4] Although the mercury removal potential is highly coal- and site-specific, long-term removal levels of over 90% were achieved during several tests. During these evaluations, the mercury removal potential, balance-of-plant impacts, and cost were determined for many different plants. This research allowed ACI to move from the research stage to a fully commercial technology; systems are currently being installed nationwide.

WP&L's Edgewater Generating Station installed one of the first commercial mercury control systems in the U.S.—an ACI system with a target goal of 70% mercury removal. The system was tested to determine its capability to reduce mercury emissions and to determine balance-of-plant impacts. Carbon injection was tested upstream and downstream of the air preheaters (APH) and with different sorbents. The goal of the testing was to identify the optimal operating conditions that would remove 70% of the mercury compounds from the flue gas.

WP&L EDGEWATER COMMERCIAL ACI SYSTEM

WP&L Edgewater Plant Description

Table 1 lists the key operating parameters for the Edgewater Generating Station.

Table 1. Key operating information for the WP&L Edgewater Generating Station.

Plant Name	Edgewater Generating Station Unit 5
Location	Sheboygan, Wisconsin
Unit Size	Nominal 380 GMW
Coal Type	PRB
Particulate Control	ESP (CE Walther Rigid Frame with SCA of 564 ft^3/kacfm)
Design Flue Gas Flowrate (APH Outlet)	1,700,000 ACFM at 280 ºF

ACI Project Overview

There were several goals set for the ACI project:

- Meet regulated emissions targets
- Identify injection rates necessary to meet emissions target
- Operate system with a minimum increase of particulate emissions and opacity
- Maintain fly ash sales
- Minimize capital expense
- Meet budget of $9,500/MW

The ACI project was completed on a fast track schedule. The order for the system was placed in June 2007. Site work began in October 2007. The system was delivered in December 2007, with installation activities continuing through January 2008. System checkout and startup activities were conducted during the month of February 2008, with performance testing in February and March. The total installed costs of the Edgewater Unit 5 ACI system was approximately $8,000/MW.

ACI System Description

Table 2 lists important information about operation of the ACI system.

Table 2. ACI system description.

Plant Name	Edgewater Generating Station Unit 5
Sorbent	Halogenated Powdered Activated Carbon
Design Feed Rate*	820 lb/hr (8 lb/MMacf APH outlet basis)
Storage Capacity at Design Feed Rate	14 days at 820 lb/hr
Sorbent Delivery	40,000-lb bulk, self-unloading pneumatic trucks

*PAC injection rate is based on APH outlet flue gas since little if any Hg is removed at temperatures above 450 ºF. The rational for APH inlet injection is for improved sorbent distribution and to make the PAC available to remove Hg as soon as the temperature reaches an effective level, typically starting in the cold end of the APH. Therefore, the injection concentration is based on the flue gas volume after the air preheater.

Figure 1. Edgewater Unit 5 ACI system silo.

The ACI system designed for Edgewater Unit 5 includes a 14' diameter storage silo with an eave height of 95' from the foundation (see Figure 1). The silo is composed of two separate modules. The upper module (i.e., Storage Module) is 78' in length and has a working volume of 11,205 ft^3. The lower module (i.e., Process Equipment Module (PEM)) is used to house the process equipment and main control panel. The PEM is approximately 17' feet in height and is composed of three separate rooms: feeder room, blower room, and electrical room. Figure 2 below shows the installation of the lower section.

Figure 2. Installation of PEM.

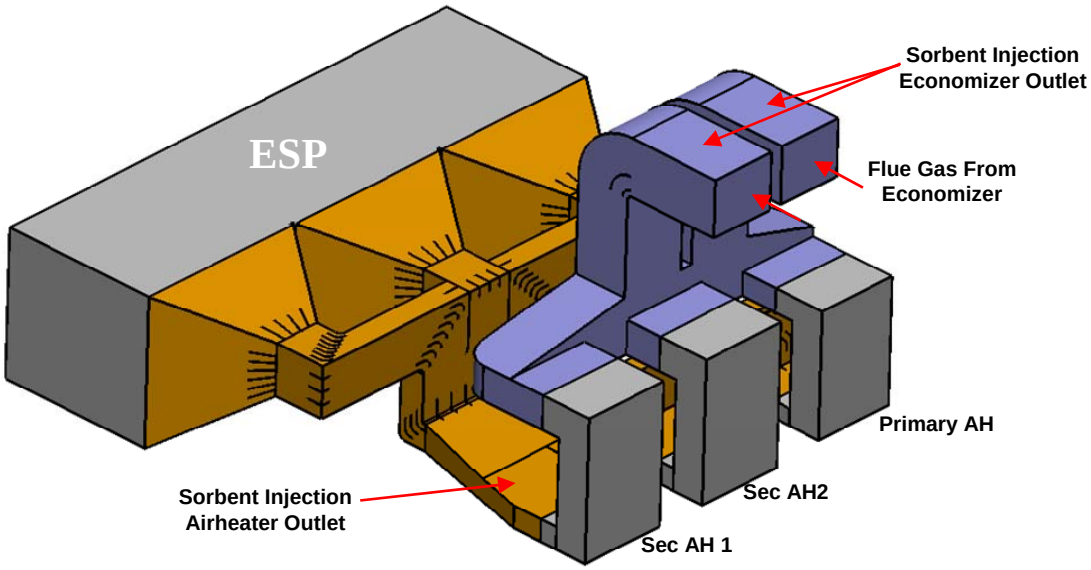
The feeder room consists of four gravimetric feeders, each with the capacity to deliver up to 1000 lb PAC/hr. After initial testing results showed high mercury removal at relatively low injection rates, an in-line gear-reducer was installed to allow more precise control at the lower rates and decreasing the feed capacity of each feeder to approximately 225 lb/hr. The feeders are controlled by a PLC with a touch screen user interface in the feeder room.

The lower section of the PEM consists of a blower room and electrical room. The blower room houses four regenerative blowers that provide the conveying air. Also located in the blower room are the discharge piping, various process instrumentation, and eductors. All the power and signal wiring from the blower and feeder rooms is routed to the electrical room and terminated inside the main control panel.

Each room is insulated and includes multiple silo penetrations for connections to plant utilities and system HVAC. The system was designed in accordance with International Building Code 2000 Edition, National Electric Code, OSHA, etc. The system is designed to have two 50% operating trains and two spare trains for system redundancy. Switching from one train to another is accomplished using pneumatically actuated diverter valves. Trains are rotated periodically to ensure even product flow from the silo and even wear.

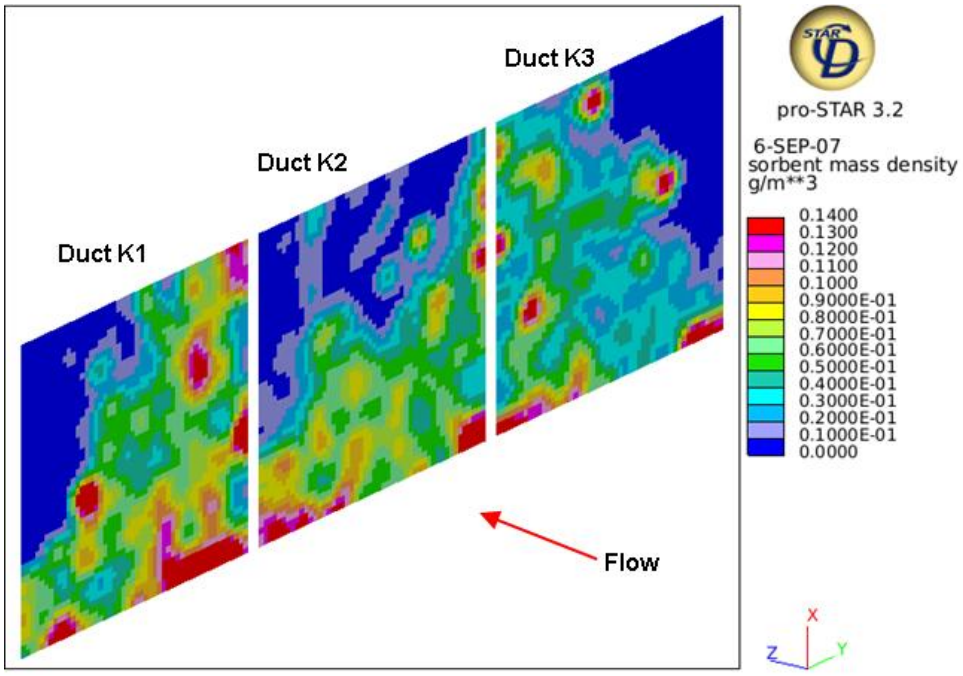
The Edgewater ACI system was designed with the capability to inject powdered activated carbon (PAC) at either the economizer outlet (APH inlet) or the APH outlet. A Computational Fluid Dynamic (CFD) model was conducted to help predict particle distribution at various locations along the ductwork and locate injection lances for optimum distribution. Edgewater Unit 5 is equipped with two (2) economizer outlet ducts that converge into a header duct just upstream of three (3) air preheater modules. Figure 3 shows the geometric model built for the CFD model.

Figure 3. Edgewater Unit 5 – CAD model.



The PAC distribution plot showing the mass density of the PAC particles in the flue gas stream is shown below. The intent is to distribute the PAC proportionally to the flue gas by the time it enters the ESP. Once the particles are injected, they tend to streamline with the flue gas flow. Thus, the sorbent injection concentration across the ESP inlet planes varies with flue gas distribution so that optimal distribution may not be feasible at all boiler loads. Injection at the economizer inlet takes advantage of turbulence through and across the APH to mix the PAC with the flue gas. The depth of the economizer outlet ducts (17’6”) required two injection lances per each of the 12 ports in a staggered arrangement to spread the PAC over the cross section.

Figure 4. Sorbent mass density contour plot (sorbent injection at the economizer outlet duct).



For the air preheater outlet location, it was determined that due to the shallow depth (6'9"), one lance per each of 16 ports with a staggered orientation provided sufficient PAC distribution prior to entering the ESPs. The sorbent mass density plot for the air heater outlet location showed similar contour patterns with respect to the economizer outlet injection location.

Figure 5. Sorbent mass density contour plot (sorbent injection at air preheater outlet).

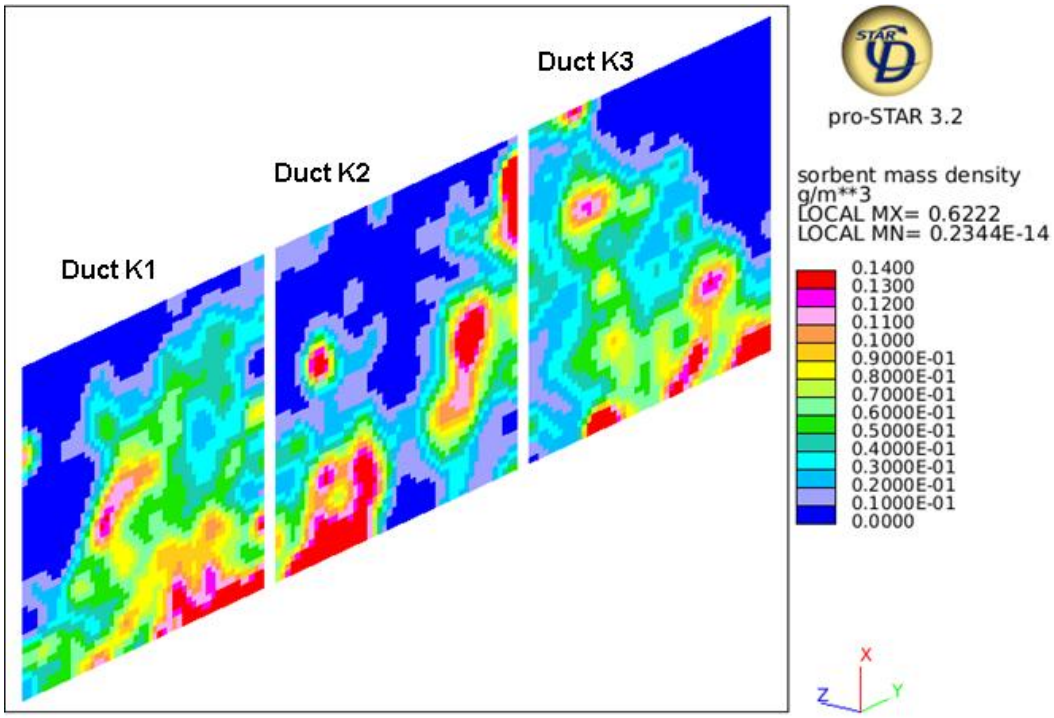
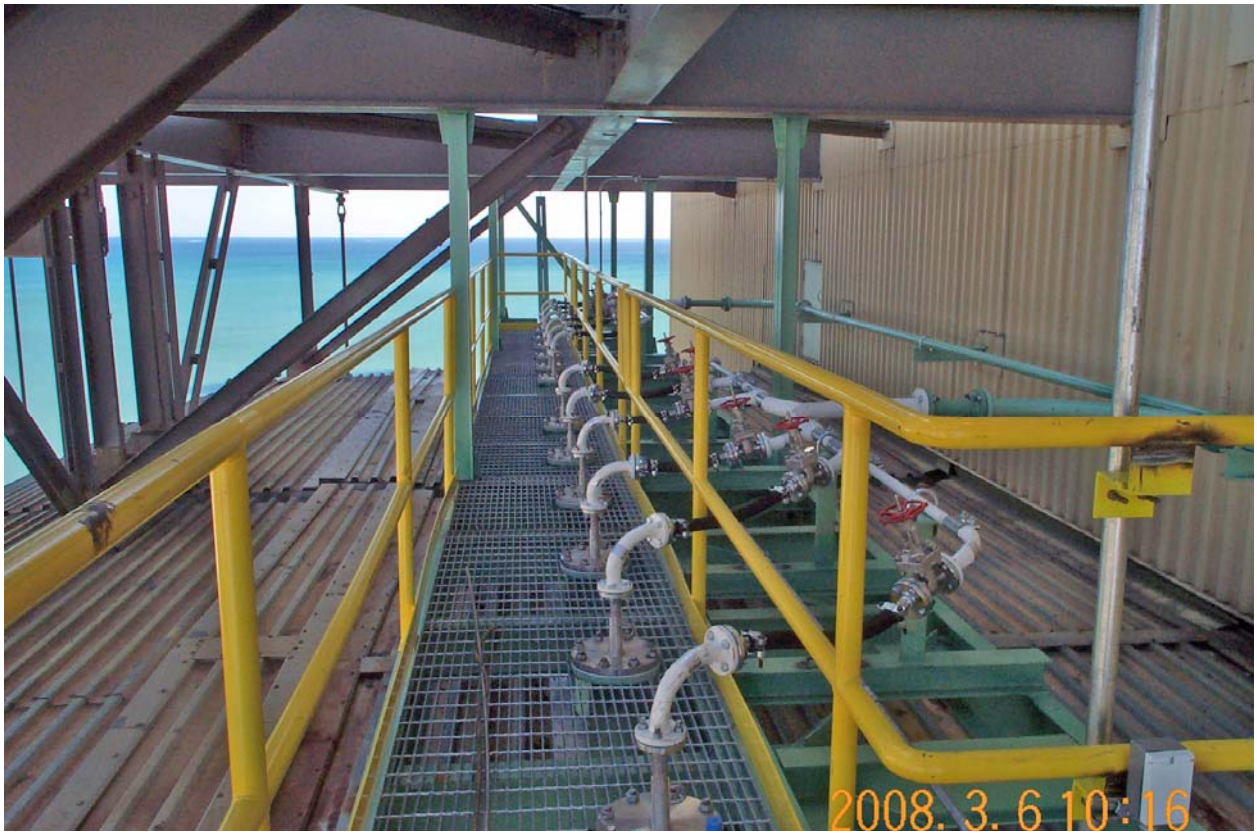


Figure 6. Sorbent injection manifold – economizer outlet.



TESTING AND RESULTS

Once the ACI system was successfully installed at Edgewater, WP&L conducted a series of parametric tests. Three major operational parameters were evaluated:

- Injection Location
  - Upstream of the APH (economizer outlet ducts)
  - Downstream of the APH
- Injection Rate (50–800 lb/hr)
- Sorbent
  - Norit DARCO® Hg-LH
  - Calgon FLUEPAC®-CF PLUS

Mercury Measurement

The stack mercury measurements were recorded with a TEKRAN mercury continuous emissions monitor.

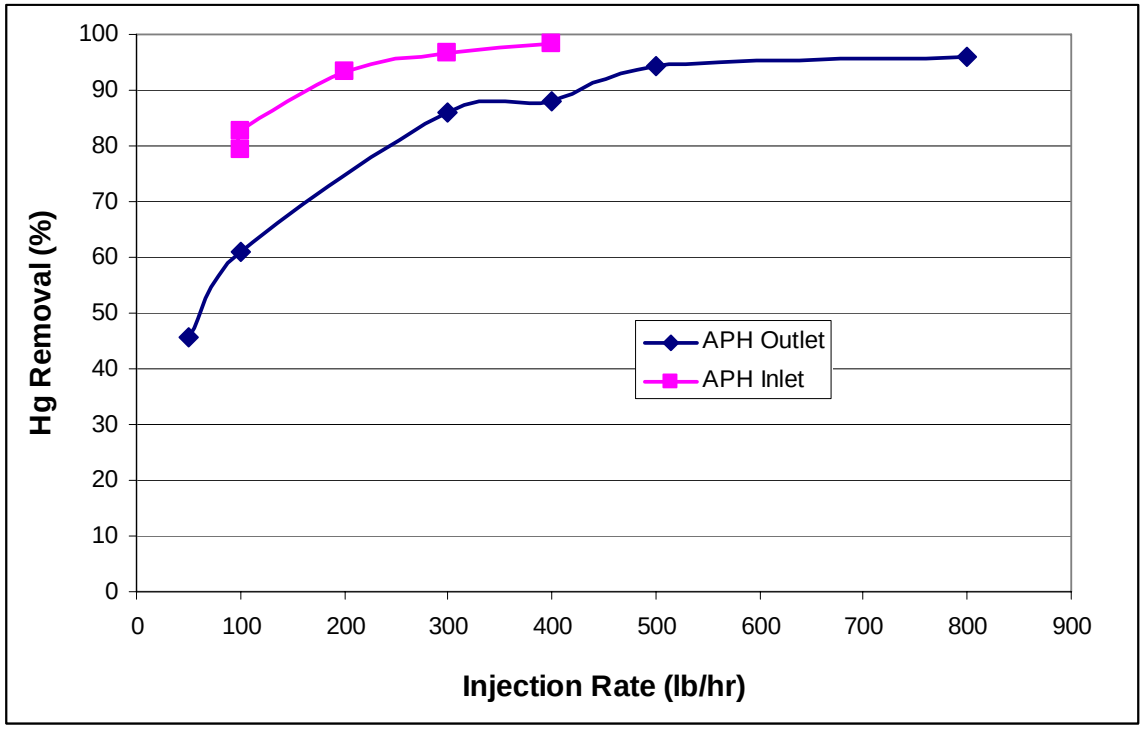
Baseline Testing

In late February 2008, baseline tests were conducted to determine the total mercury in the flue gas under standard operating conditions. Without sorbent injection, mercury concentrations at the stack ranged from 4 µg/m^3 to approximately 8 µg/m^3, with an average value of 6.4 µg/m^3.

Injection Location Comparison

The first round of parametric testing included sorbent injection both upstream (inlet) and downstream (outlet) of the APH. The air temperature at the APH inlet was approximately 700 ºF, while the temperature at the outlet ranged from 290–300 ºF and full-load flue gas flowrate as measured by the stack CEMs was approximately 1.44 MMacf. Figure 7 compares the removal levels when injecting Norit DARCO® Hg-LH upstream and downstream of the APH. At the same injection rate, higher mercury removal levels were achieved by injecting at the APH inlet, most likely due to superior mixing and PAC distribution.

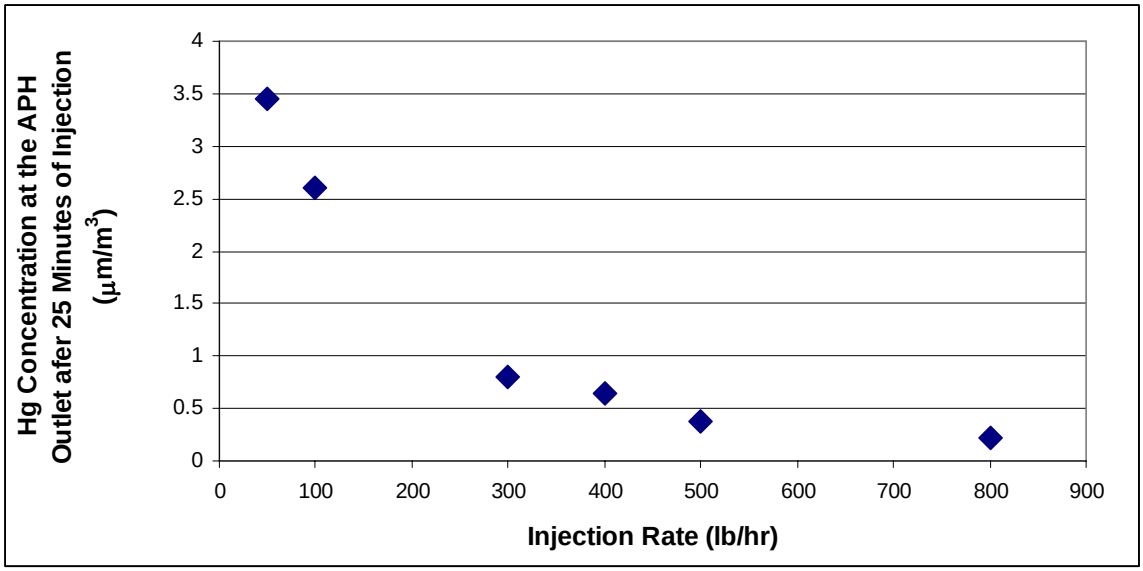
Figure 7. Mercury removal upstream and downstream of the APH.



Injection Rate

Parametric tests were conducted to determine the necessary injection rate of PAC to achieve the desired mercury removal level (70%). Figure 8 shows the mercury content of the flue gas when Norit's DARCO® Hg-LH was injected at several different rates.

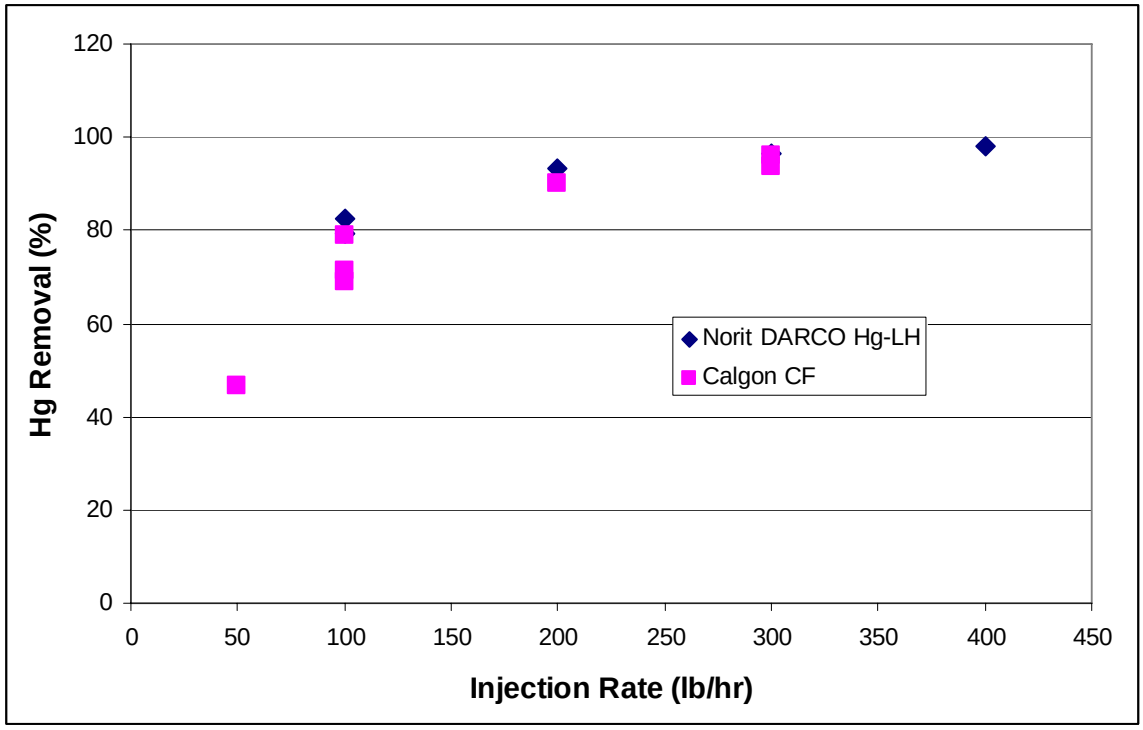
Figure 8. Mercury emission levels at different injection rates of DARCO® Hg-LH.



Sorbent Comparison

DARCO® Hg-LH and Calgon FLUEPAC®-CF PLUS brominated PAC sorbents were tested at the APH inlet injection location . Figure 9 compares the mercury removal at different injection rates for these two sorbents and indicate very similar performance.

Figure 9. Mercury removal levels for DARCO® Hg-LH and Calgon FLUEPAC®-CF PLUS.



To meet the goal of 70% mercury removal, Edgewater could use either sorbent injected at the APH inlet at rates of approximately 100 lb/hr which was equivalent to 1.15 lb/MMacf at measured gas flows (APH outlet basis). If regulations become more strict in the future, the installed ACI system is capable of meeting 90% removal, which will require an injection rate of approximately 210 lb/hr (2.45 lb/MMacf, APH outlet basis) of either sorbent.

O&M Costs

Annual carbon consumption at 100 lb/hr and using a 90% capacity factor is ~789,000 lb/year. Typical power consumption with two trains operating and silo enclosure space heaters running is approximately 142 kW.

Particulate Emissions Impacts

Particulate emissions and opacity impacts were assessed during the initial testing of the ACI system to determine the possibility of significant particulate emission increases. A continuous particulate emissions monitor was installed in the stack to monitor PM-10 emissions before and during injection trials to assess these impacts on Unit 5. At the injection rates of 100 to 210 lb/hr, no significant increase in PM-10 emissions or opacity was measured.

Fly Ash Impacts

Fly ash from Edgewater Unit 5 is currently sold to the concrete industry. Maintaining ash sales and beneficially reusing ash is an extremely important consideration for WP&L with any mercury emissions control technology. Ash sampling was conducted during the injection trials and sampled for foam index. At the 100 lb/hr injection rate, while Norit's DARCO® Hg-LH did not produce an acceptable flyash for concrete use, the Calgon concrete-friendly FLUEPAC®-CF PLUS material yielded very promising foam index results. Continued testing and optimization is planned to determine if an acceptable flyash can be produced on a consistent and long-term basis.

SUMMARY

WP&L has installed one of the first commercial activated carbon injection systems for mercury removal in the U.S. The system was delivered in late 2007 and was installed in early 2008. It was installed with two injection locations: the air preheater inlet and outlet. CFD modeling was used to evaluate the PAC distribution in the flue gas. Before beginning permanent operation of the system, WP&L opted to conduct parametric tests to determine the mercury removal levels for different injection locations, injection rates, and sorbents. Removal levels were higher at the APH inlet. The two sorbents, Norit's DARCO® Hg-LH and Calgon's FLUEPAC®-CF PLUS, had nearly the same mercury removal performance. Both sorbents could meet the 70% removal target with an APH inlet injection rate of approximately 100 lb/hr. At this injection rate, no significant increases in particulate emissions or opacity were experienced. However, additional testing will be required to determine if the flyash from Edgewater Unit 5 can remain saleable on a continuing basis with ACI. The project was completed for $8,000/MW, which was below the $9,500/MW that was budgeted.

REFERENCES

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KEY WORDS

Mercury Control
Activated Carbon Injection
Commercial ACI
Sorbent Injection
Coal