

**Waste Coal Fines Reburn for NO_x and Mercury
Emission Reduction**

Final Technical Report

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Stephen A. Johnson, Chetan Chothani and Bernard P. Breen

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**Breen Energy Solutions
104 Broadway Street
Carnegie, PA 15106
(412) 489-3020**

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Abstract

Injection of coal-water slurries (CWS) made with both waste coal and bituminous coal was tested for enhanced reduction of NO_x and Hg emissions at the AES Beaver Valley plant near Monaca, PA. Under this project, Breen Energy Solutions (BES) conducted field experiments on these emission reduction technologies by mixing coal fines and/or pulverized coal, urea and water to form slurry, then injecting the slurry in the upper furnace region of a coal-fired boiler. The main focus of this project was use of waste coal fines as the carbon source; however, testing was also conducted using pulverized coal in conjunction with or instead of waste coal fines for conversion efficiency and economic comparisons.

The host site for this research and development project was Unit #2 at AES Beaver Valley cogeneration station. Unit #2 is a 35 MW Babcock & Wilcox (B&W) front-wall fired boiler that burns eastern bituminous coal. It has low NO_x burners, overfire air ports and a urea-based selective non-catalytic reduction (SNCR) system for NO_x control. The back-end clean-up system includes a rotating mechanical ash particulate removal and electrostatic precipitator (ESP) and wet flue gas desulfurization (FGD) scrubber.

Coal slurry injection was expected to help reduce NO_x emissions in two ways:

1. Via fuel-lean reburning when the slurry is injected above the combustion zone.
2. Via enhanced SNCR reduction when urea is incorporated into the slurry.

The mercury control process under research uses carbon/water slurry injection to produce reactive carbon in-situ in the upper furnace, promoting the oxidation of elemental mercury in flue gas from coal-fired power boilers. By controlling the water content of the slurry below the stoichiometric requirement for complete gasification, water activated carbon (WAC) can be generated in-situ in the upper furnace. As little as 1-2% coal/water slurry (heat input basis) can be injected and generate sufficient WAC for mercury capture.

During July, August, and September 2007, BES designed, procured, installed, and tested the slurry injection system at Beaver Valley. Slurry production was performed by Penn State University using equipment that was moved from campus to the Beaver Valley site. Waste coal fines were procured from Headwaters Inc. and transported to the site in Super Sacks. In addition, bituminous coal was pulverized at Penn State and trucked to the site in 55-gallon drums.

This system was operated for three weeks during August and September 2007. NO_x emission data were obtained using the plant CEM system. Hg measurements were taken using EPA Method 30B (Sorbent Trap method) both downstream of the electrostatic precipitator and in the stack. Ohio Lumex Company was on site to provide rapid Hg analysis on the sorbent traps during the tests.

Key results from these tests are listed below:

- Coal Fines reburn alone reduced NO_x emissions by 0-10% with up to 4% heat input from the CWS. However, the NO_x reduction was accompanied by higher CO emissions. The higher CO limited our ability to try higher reburn rates for further NO_x reduction.
- Coal Fines reburn with Urea (Carbon enhanced SNCR) decreased NO_x emissions by an additional 30% compared to Urea injection only.
- Coal slurry injection did not change Hg capture across the ESP at full load with an inlet temperature of 400-430 °F. The Hg capture in the ESP averaged 40%, with or without slurry injection; low mercury particulate capture is normally expected across a higher temperature ESP because any oxidized mercury is thought to desorb from the particulate at ESP temperatures above 250°F.
- Coal slurry injection with halogen salts added to the mixing tank increased the Hg capture in the ESP to 60%. This significant incremental mercury reduction is important;
 - to improved mercury capture with hot-side ESP operation and
 - wherever hindrance from sulfur oxides limit mercury reduction, because the higher temperature is above sulfur oxide dew point interference.

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Executive Summary

Injection of coal-water slurries made with both waste coal and bituminous coal was tested for enhanced reduction of NO_x and Hg emissions at the AES Beaver Valley plant near Monaca, PA. Under this project, Breen Energy Solutions (BES) conducted field experiments on these emission reduction technologies by mixing coal fines and/or pulverized coal, urea and water to form slurry, then injecting the slurry in the upper furnace region of a coal-fired boiler. The main focus of this project was use of waste coal fines as the carbon source; however, testing was also conducted using pulverized coal in conjunction with or instead of waste coal fines for conversion efficiency and economic comparisons.

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Coal slurry injection is expected to help reduce NO_x emissions in two ways:

1. Via fuel-lean reburning when just the slurry is injected above the combustion zone.
2. Via enhanced SNCR reductions when urea is incorporated into the slurry.

The mercury control process under research uses carbon/water slurry injection to produce reactive carbon in-situ in the upper furnace, promoting the oxidation of elemental mercury in flue gas from coal-fired power boilers. By controlling the water content of the slurry below the stoichiometric requirement for complete gasification, water activated carbon (WAC) can be generated in-situ in the upper furnace. As little as 1-2% coal/water slurry (heat input basis) can be injected and generate sufficient water activated carbon for mercury capture.

The carbon is activated by the surface reaction between carbon and water at high temperatures and locally oxygen-deficient conditions found in the upper furnace. These carbon surfaces are different from the carbon surfaces from coal fired through the main burners that experience the combustion process. Carbon surfaces that pass through the combustion zone are typically less active, because the high temperature combustion process tends to vitrify what little carbon that is not oxidized.

During July, August, and September 2007, BES designed, procured, installed, and tested the slurry injection system at Beaver Valley. Slurry production was performed by Penn State University using equipment that was moved from campus to the Beaver Valley site. Waste coal fines were procured from Headwaters Inc. and transported to the site in Super Sacks. In addition, bituminous coal was pulverized at Penn State and trucked to the site in 55-gallon drums.

This system was operated for three weeks during August and September 2007. NO_x emission data were obtained using the plant CEM system. Hg measurements were taken using speciated sorbent traps both downstream of the electrostatic precipitator and in the stack. Ohio Lumex Company was on site to provide rapid Hg analysis on the sorbent traps during the tests.

Key results from these tests are listed below:

- Coal Fines reburn alone reduced NO_x emissions by 0-10% with up to 4% reburn rate. However, the NO_x reduction was accompanied by higher CO emissions. The higher CO limited our ability to try higher reburn rates for further NO_x reduction.
- Coal Fines reburn with Urea (Carbon enhanced SNCR) decreased NO_x emissions by an additional 30% compared to Urea injection only.
- Coal slurry injection did not change Hg capture across the ESP at full load with an inlet temperature of 400-420 °F. The Hg capture in the ESP was 40%, with or without slurry injection.
- Coal slurry injection with halogen salts added to the mixing tank increased the Hg capture in the ESP to 60%.

Report Details

Introduction

Injection of coal-water slurries made with both waste coal and bituminous coal was tested for enhanced reduction of NO_x and Hg emissions at the AES Beaver Valley plant near Monaca, PA. Under this project, Breen Energy Solutions (BES) conducted field experiments on these emission reduction technologies by mixing coal fines and/or pulverized coal, urea and water to form slurry, then injecting the slurry in the upper furnace region of a coal-fired boiler. The main focus of this project was use of waste coal fines as the carbon source; however, testing was also conducted using pulverized coal in conjunction with or instead of waste coal fines for conversion efficiency and economic comparisons.

The host site for this research and development project was Unit #2 at AES Beaver Valley cogeneration station. Unit #2 is a 35 MW Babcock & Wilcox (B&W) front-wall fired boiler that burns eastern bituminous coal. It has low NO_x burners, overfire air ports and a urea-based selective non-catalytic reduction (SNCR) system for NO_x control. It has a wet flue gas desulfurization system for SO₂ emission control and an electrostatic precipitator for particulate emissions and opacity control.

Coal slurry injection was expected to help reduce NO_x emissions in two ways:

1. Via fuel-lean reburning when just the slurry is injected above the combustion zone.
2. Via enhanced SNCR reductions when urea is incorporated into the slurry.

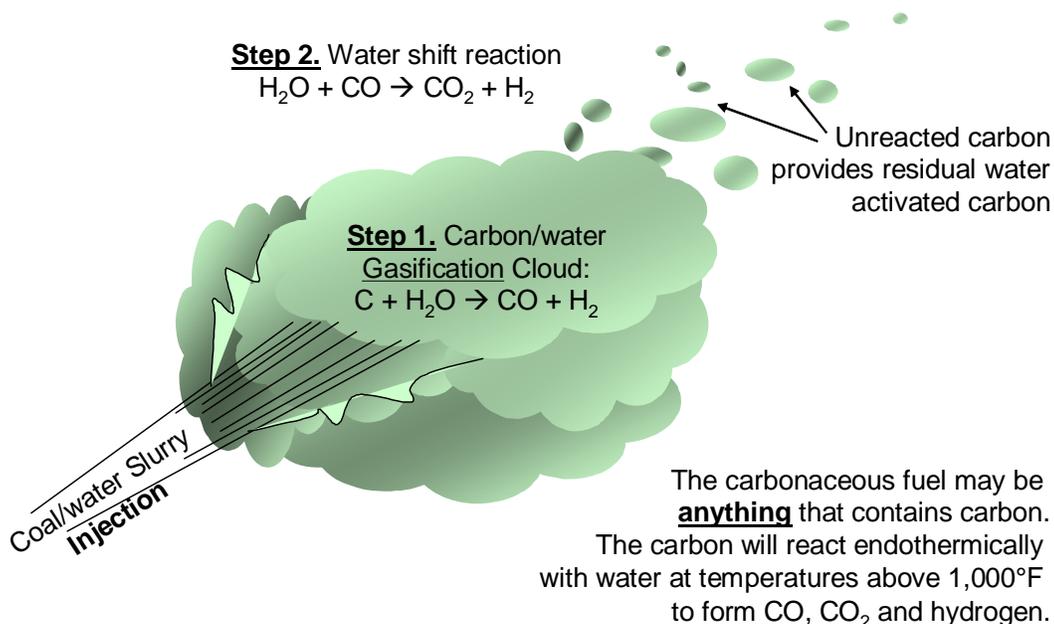
Fuel lean reburning produces reactive species like: H₂, CO, and CH, CN, OH radicals by both devolatilization and classic coal/water reactions of the char with the water under localized hot, oxygen-deficient conditions. These species will convert a portion of the NO_x formed in the burner zone to N₂. Similarly, SNCR is enhanced as the competing urea oxidation reaction is stifled and more of the reagent is available to reduce NO_x.

The mercury control process under research uses carbon/water slurry injection to produce reactive carbon in-situ in the upper furnace, promoting the oxidation of elemental mercury in flue gas from coal-fired power boilers. By controlling the water content of the slurry below the stoichiometric requirement for complete gasification, water activated carbon (WAC) can be generated in-situ in the

upper furnace. As little as 1-2% coal/water slurry (heat input basis) can be injected and generate sufficient water activated carbon for mercury capture.

The carbon is activated by the surface reaction between carbon and water at high temperatures and locally oxygen-deficient conditions found in the upper furnace. These carbon surfaces are different from the carbon surfaces from coal fired through the main burners that experience the combustion process. Carbon surfaces that pass through the combustion zone are typically less active, because the high temperature combustion process tends to vitrify what little carbon that is not oxidized. A schematic of the WAC generation process and reactions is shown in Figure 1 below.

Figure 1. Coal-Water Gasification Reaction



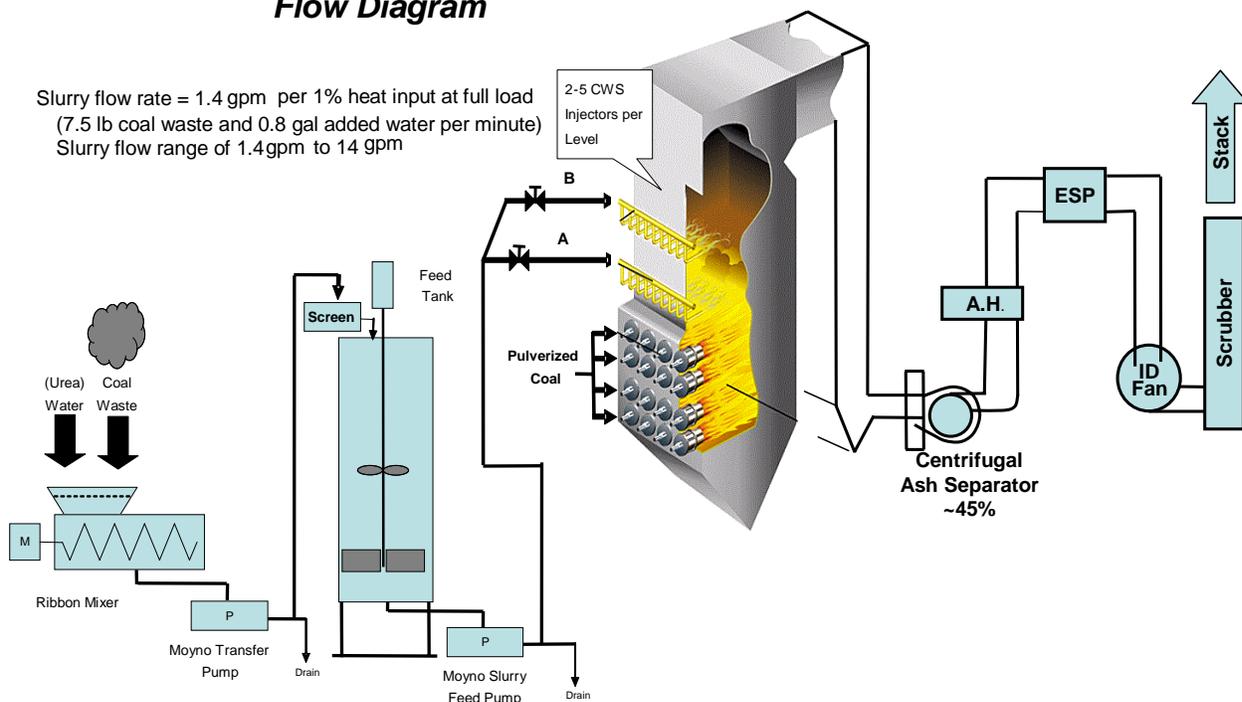
The presence of heterogeneous carbon in the fly ash attracts some of the chlorinated species from the flue gas. Such chlorinated species form reactive sites on the carbon that wholly or partially oxidize mercury, which ultimately appears in the flue gas as HgCl₂. This heterogeneous process enhances the number and effectiveness of reaction sites available for the oxidation of vapor phase, elemental mercury to HgCl₂.

Approach

During the summer Quarter (July-August-September), BES designed, procured, installed, and tested the slurry injection system at Beaver Valley. Slurry production was performed by Penn State University using equipment that was moved from campus to the Beaver Valley site. Waste coal fines were procured from Headwaters, Inc and transported to the site in Super Sacks. In addition, bituminous coal was pulverized at Penn State and trucked to the site in 55-gallon drums. A schematic of the coal slurry production and injection system is shown as Figure 2.

Figure 2 - Coal Waste Slurry Return

Flow Diagram



This system was operated for three weeks during August and September 2007. NO_x emission data was obtained using the plant CEM system. Hg measurements were taken using speciated sorbent traps both downstream of the electrostatic precipitator and in the stack. Ohio Lumex Company was on site to provide rapid Hg analysis during the tests.

Hg analysis was done in accordance with EPA Method 30B, also known as the Sorbent Trap Method. The sorbent traps were filled with iodated coconut shell carbon and exposed to a measured volume of flue gas for an hour. The tubes were then passed on to Ohio Lumex who analyzed them on site using their RP-M324 Analyzer. Each trap was cut and the contents transferred to a quartz ladle. The ladle was placed into the analyzer and heated to 800 C to release the Hg. A portion of the sample released went through a catalytic conversion chamber and on to a cold-vapor Atomic Absorption Spectrometer for measurement of total mercury. A portion of the sample bypassed the catalytic conversion chamber so that elemental mercury could also be determined. Oxidized mercury could then be inferred by difference. This method only detects gas-phase Hg, so particulate Hg was not measured.

Results and Discussion

Initial testing was successful in achieving steady coal-water slurry flow without plugging the hoses and injectors. This is no mean feat. The coal waste size distribution was only 32 % larger than 50-mesh (300 microns/ 0.012 inches), but some of the chunks were more like ¼-inch. Care was taken to assure that these “rocks” stayed in the tank.

Several injector designs were tested during the first week. We tried 4 different nozzle sizes and various spray angles. The nozzles were air assisted, so air pressure could be increased to produce finer droplet sizes. Slurry pressure also influenced atomization, and this depended on the coal concentration. Higher coal concentrations caused more pressure loss in transit from the Moyno pump to the injectors. Figure 3 shows a photo of a successful atomizer in operation.



Figure 3. Coal Slurry Spray

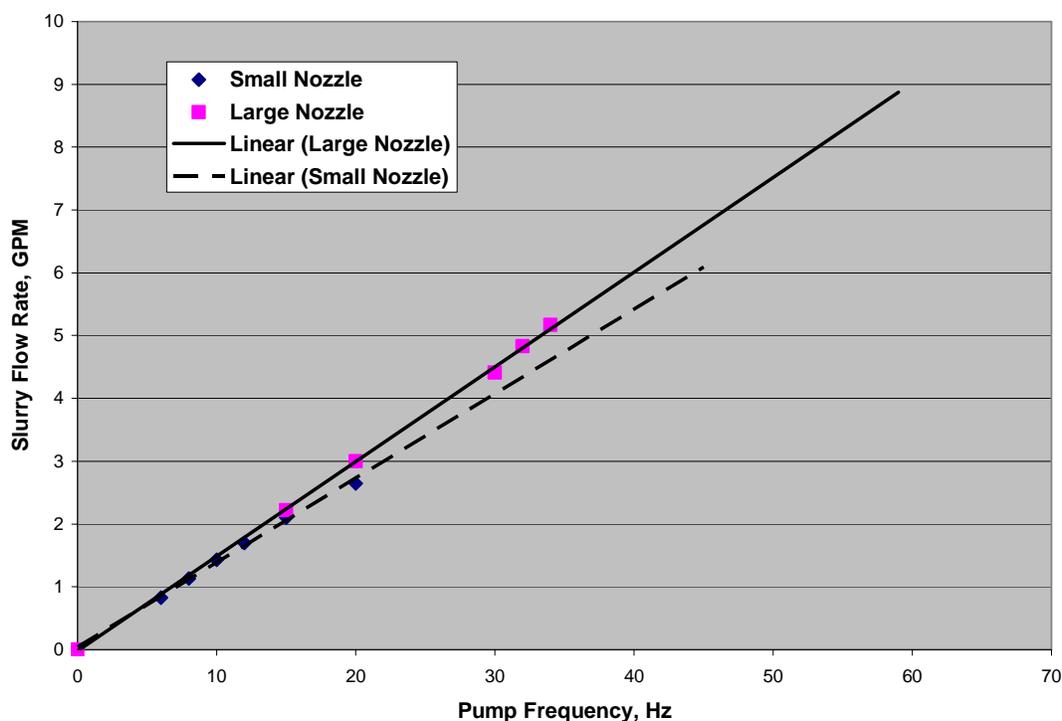
Two elevations on the rear wall of the furnace were used for slurry injection. Elevation 2B was located about 18-ft above the overfire air ports and had 3 injection ports. Elevation 2A was located about 8-ft above the OFA ports and offered 4 injection ports. The lower injector elevation accessed

higher furnace temperatures expected to enhance the reburning process for NO_x control, while the lower temperatures in the upper ports were expected to enhance SNCR effectiveness for NO_x control and carbon activation for Hg control.

Care was taken during operation to avoid spraying slurry near the furnace walls. Injectors were pushed several inches past the water-wall tubes to avoid impingement on the rear wall, and angled toward the center of the furnace to avoid side wall impingement.

Nozzle flow rates were calibrated to the speed of the Moyno feed pump as shown on Figure 4. Operation on a single nozzle went as high as 9 GPM, so some extrapolation of the calibration was required.

Figure 4. Injection Nozzle Calibration



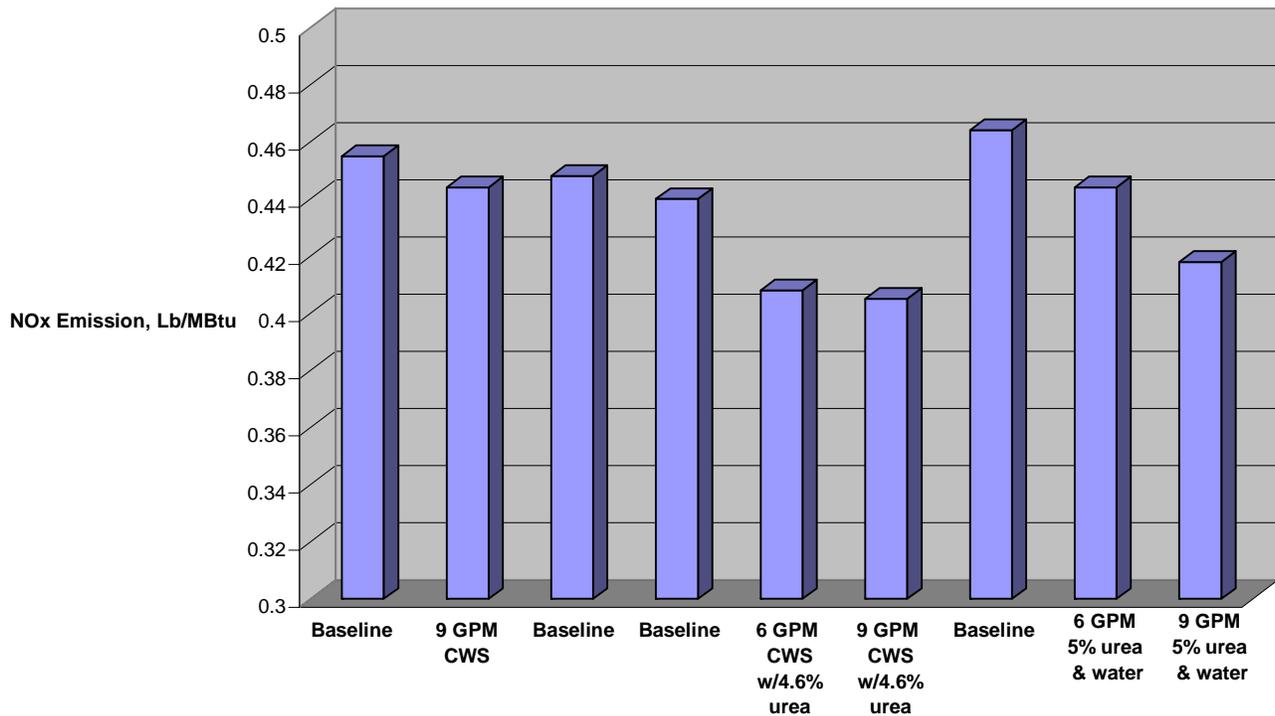
The slurry solids content was varied during initial injection tests. Just one injector was used at a time during the first week as we worked out the details of slurry mixing, transfer to the feed tank, and injection. It took several days to home in on a successful range of coal concentrations (less than 50%) and to develop procedures to trap large coal particles so that plugging of pumps, nozzles and transfer lines could be avoided.

Nitric Oxide Reduction Testing and Results

Once successful operation was established, the second week was devoted to testing the NO_x reduction enhancement made possible by CWS injection. The results are shown on Figures 5 and 6 and summarized below.

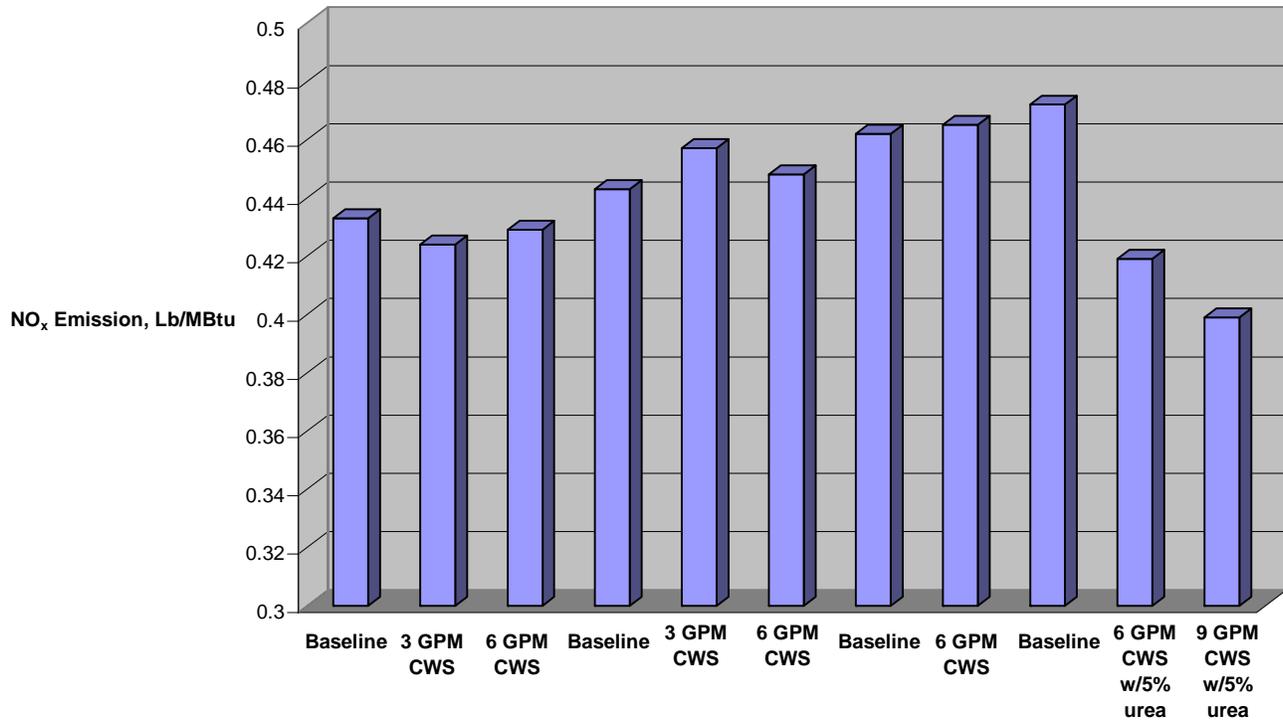
There was no NO_x emission reduction while injecting 45-50 % coal-water slurry (CWS) at rates up to 9 GPM at either injection elevation 2A or 2B. However, NO_x reductions improved by over 30% when urea was added to the CWS as compared to injected urea and water by itself. It can be seen that without CWS the NO_x emissions were about 0.46 lb/MBtu. Adding urea at level 2A brought the NO_x down to 0.44 lb/MBtu (the low percentage reduction was due to some urea oxidation to NO_x at the higher gas temperature expected at that lower (hotter) furnace elevation). When the same amount of urea was contained in the slurry, NO_x emission dropped to 0.40 lb/MBtu because the fuel-rich region created by the coal scavenged oxygen that would have produced NO_x.

Figure 5. NO_x Emissions at Beaver Valley Unit 2 with Level 2A Injection



Results were similar when injecting at elevation 2B. Here the NO_x was reduced from above 0.46 lb/MBtu down to below 0.40 lb/MBtu (17% reduction) when injecting both CWS and urea at this lower temperature upper injection level.

Figure 6. NO_x Emissions at Beaver Valley Unit 2 with Level 2B Injection



The NO_x results were achieved using just one CWS injector. Tests were attempted with two injectors, but plugging occurred. The boiler also reached the limit on the amount of CWS that could be injected through a single injector as evidenced by unacceptable CO emissions (300-600 ppm) with CWS flow of 9 GPM. Therefore, efforts were made to use multiple injectors to achieve better dispersion of the CWS across the boiler.

Plugging was expected to be less problematic at lower CWS solids flow. Therefore, many of the test runs during the last week of testing targeted 25 % coal content in the slurry.

Our tests have shown enhanced NO_x reductions with urea in the CWS. The coal percentage was around 50% for these tests. The enhancement was due to preferential reaction of flue gas oxygen with the coal: at higher furnace temperatures less of the urea is burned to form NO_x and more urea participates in NO_x reduction.

Another test limitation was that we could only inject two batches of CWS per day. This gave us about an hour of operation at 9 GPM when we filled the 1000-gallon feed tank to above the upper impeller. Since it takes about three hours to produce this much CWS, timing only allowed a morning test run and an afternoon test run. We were able to squeeze in a third urea-only test on a few days.

Mercury Oxidation and Capture Results

NO_x emissions were measured, but the focus turned to Hg tests during the week of 10 September 2007. Method 30B was used to measure Hg downstream of the precipitator as well as in the stack. Coal samples taken twice daily from the coal feeders were also analyzed for Hg content to define the total amount of Hg in the flue gas leaving the boiler.

Several coals were burned during the three weeks of testing. As a result, Hg content of the coal varied from 9 to 24 lb/TBtu as shown in Table 1 below. The average Hg content was 12.8 lb/MBtu for all samples analyzed.

We did not expect any Hg reduction across the precipitator since it was operating at 400 to 430 °F where carbon has limited Hg capacity. As shown on Table 1 below, this was not the case at Beaver Valley Unit 2. Under baseline conditions without slurry injection, Hg content of the flue gas leaving the precipitator averaged about 6.6 lb/TBtu, a reduction of about 48 %. The Hg reduction for each individual test is provided in Table 1 and ranged from 29 to 67%. Though surprising to us, this result was not surprising to plant personnel. Hg testing performed by AES back in 2004 (also shown in the Table) had similar results.

It is also interesting to note that most of the Hg (50 to 70%) was in the oxidized form (HgCl₂) downstream of the precipitator. The plant burns high-chlorine, medium-sulfur bituminous coals from several nearby mines. HCl averaged about 720 ppm in the coal during the tests. The unburned carbon in the fly ash is responsible for both Hg oxidation and capture. The LOI measured during these baseline tests ranged from 9 to 20 percent.

Injecting CWS into the upper furnace added only 5 to 7 percent to the LOI measured in the fly ash. In most cases, the addition of CWS did not have a large effect on either Hg oxidation or Hg capture across the precipitator. Hg removal across the ESP averaged 51 percent with CWS injection and 48 percent without it; While Hg oxidation leaving ESP averaged 52 percent with CWS injection and 68 percent without it. Indicating the more of the oxidized mercury was capture in the high temperature ESP.

We had a direct comparison of Hg capture with and without CWS injection on 4 test days. These data are separated out on Table 2. In general, the Hg capture was slightly better across the precipitator with the CWS addition. However, Hg oxidation of the remaining Hg was significantly less, indicating that some of the oxidized mercury may have adsorbed unto the captured ESP particulate. The lower Hg oxidation had a negative impact on the amount of Hg captured by the wet FGD system.

Table 1. Summary of Hg Test Results

Date/Time	Hg Fuel, Lb/TBtu	Hg After ESP $\mu\text{g}/\text{Nm}^3$	Hg After ESP Lb/TBtu	% Reduction Across ESP (by difference)	% Oxidized	Hg, Stack, $\mu\text{g}/\text{Nm}^3$	Hg, Stack, Lb/TBtu	% Reduction Across Scrubber	% Oxidized
2004	9.8		3.5	64	72		2.5	29	8
8/13/07	13.5	10.8	8.6	36	75				
8/14, 14:05-15:05	13.8	10.85	8.7	37	62	3.08	2.5	71.6	25
8/14, 16:36-17:23	13.2	10.33	8.3	37	51	3.67	2.9	64.5	16
8/15, 13:30-14:29	12.7	8.91	7.1	44	61	2.44	2.0	72.6	15
8/16, 12:50-13:30	11.3	7.27	5.8	49	58	2.09	1.7	71.3	18
8/16, 15:20-16:35	11.3	7.07	5.7	50	71	2.12	1.7	70.0	7
8/16, 18:25-18:42	11.3	7.09	5.7	50	61	1.96	1.6	72.4	5
8/17, 12:05-12:35	12.8	6.72	5.4	60	51	2.23	1.8	66.8	16
8/17, 16:30-17:00	12.8	5.31	4.2	67	14	1.38	1.1	74.0	15
8/20, 15:40-16:40	20.9	12.74	10.2	51	48	3.45	2.8	72.9	6
8/20, 17:45-18:45	20.9	9.51	7.6	64	61	3.06	2.4	67.8	9
8/22, 17:45-18:27	20.9	9.10	7.3	65	73	4.12	3.3	54.8	15
8/23, 14:50-15:20	15.2	10.26	8.2	46	79	2.62	2.1	74.5	16
8/23, 17:00-17:30	15.2	8.52	6.8	55	47	3.72	3.0	56.3	9
9/12, 14:28-15:28	8.5	4.83	3.9	55	45	2.99	2.4	38.1	9
9/12, 16:40-17:40	8.8	5.67	4.5	48	65	2.28	1.8	59.8	12
9/13, 13:05-14:05	8.8	6.17	4.9	44	53	2.83	2.3	54.1	10
9/13, 15:30-16:30	8.8	7.19	5.7	35	69	2.65	2.1	63.1	13
9/13, 17:05-17:59(CaBr ₂)	8.8	4.36	3.5	60	25	3.06	2.4	29.8	8
9/14, 11:33-12:33(F.Ash)	9	8.40	6.7	25	74	2.76	2.2	67.1	14
9/14, 12:55-13:55	9	8.04	6.4	29	65	2.61	2.1	67.5	14

Note: highlighted measurements made during coal slurry injection. CaBr₂ added to CWS for 17:05 test on 9/13/07. Fly ash used instead of coal for test on 9/14/07.

Table 2. Daily Comparison of Hg Results

Date	Hg Reduction w/o CWS, %	Hg Reduction w/CWS, %	Hg Oxidation w/o CWS, %	Hg Oxidation w/CWS, %
8/20/07	64	51	61	48
8/23/07	46	55	79	47
9/12/07	48	55	65	45
9/13/07	35	44	69	53
Average	48	51	68	48

Enhancement of High Temperature Mercury Oxidation and Capture

On 13 September, based on our kinetic modeling, we added calcium bromide to the slurry in an attempt to aid Hg oxidation through the economizer temperature gradient and increase activated carbon surface capture across the higher temperature (430°F) precipitator.

For this test, the composition of CaBr₂/ CWS injected (all percentages by weight):

- 25% coal,
- 1.5% CaBr₂,
- 10.0% urea
- 63.5% water

Injecting about 6 GPM into the upper furnace was estimated equivalent to about 1.5% of the boiler heat input. Then calculating the lb CaBr₂ per lb of coal in the CWS = 0.06. Multiplying by .015 would get lb CaBr₂ per lb of coal fired = 900 ppmw. Estimate 11 lb flue gas per lb coal, the CaBr₂ would be 82 ppmw in the flue gas, and Br₂ is 160/199 (ratio of molecular weights of CaBr₂ and Br₂) or 66 ppmw. The mole percent of Br₂ in the flue gas could be estimated by multiplying by 29/160 = 12 ppmv.

The results were significant as shown on Table 1. and detailed in Table 3.

It can be seen that not only did the bromine increase the Hg capture by the precipitator, but also the fraction of oxidized Hg leaving the precipitator was also much less. It is strongly suspected that coal-derived carbon has two types of reactive sites: one that oxidizes and releases Hg and one that captures or retains Hg. This result suggests that the Br serves to preferentially attract Hg to the sites that capture Hg.

Interestingly, since the amount of Hg leaving the precipitator was lower, the wet FGD system captured less Hg when injecting Bromine in the CWS. Thus, in all three cases described in Table 3, the Hg emission as measured in the stack was about the same.

Table 3. Effect of CaBr₂ Addition on Hg Capture

	Hg Reduction across ESP, %	Hg Oxidation leaving ESP, %	Hg Reduction across wet FGD, %
No Injection	35	69	63
CWS Injection	44	53	54
CWS w/CaBr₂	60	25	30

Fly ash samples were taken from the flue gas during these tests and sent to Professional Analytical and Consulting Services, Inc (PACS) of Coraopolis, PA to assess the reactivity achieved in the LOI carbon. The amount of coal in the slurry and the slurry injection rates were varied to see the effects on Hg capture and residual carbon reactivity. One sample contained ash collected when the slurry contained ash from the centrifugal rotary as collector located upstream of the precipitator. (This ash collector collects about 50% of the fly ash leaving the boiler and has an LOI of about twice the LOI of the fly ash going on to the ESP.) The purpose of this analysis was to confirm and quantify any increase in fly ash activity toward Hg resulting from the water (CWS) activation process. The results are summarized in Table 4 below.

First, we note that only two out of the five samples taken during slurry injection showed increased surface area relative to typical fly ash unburned carbon. Furthermore, this increase in carbon reactivity could not be correlated to the total carbon injected in the slurry. For example, the samples with the least amount of coal turned out to have the highest reactivity as measured by surface area. Also, the samples taken on 20 August and 13 September had the same amount of coal addition, but greatly different surface areas. Samples with the highest surface area also scored higher in pore volume and absorption capacity. None of the samples came close to commercial activated carbon (Norit Darco FGD) in terms of reactivity.

Table 4. Summary of Carbon Reactivity

Sample Date	Sample Description	LOI, %	BET Surface Area, m ² /g	Pore Volume, cm ³ /100g	Trace Capacity, g/100 cm ³	Hg in Fly Ash, Ppm(w)
8/20/07	50% CWS @ 3 GPM	23.3	62	3.07	2.31	0.027
8/22/07	50% CWS @ 9 GPM	17.1	15	0.68	0.02	0.071
9/12/07	40% CWS @ 6 GPM	20.1	21	1.30	0.15	0.032
9/13/07	25% CWS @ 6 GPM (w 1.5% CaBr ₂)	9.1	15	0.94	0.21	0.164
9/14/07	16% ash, 8% coal CWS @ 6 GPM	19.4	59	3.24	1.45	0.052
	Typical fly ash (No injection)	11-18	22	1.22	0	---
	Norit Darco FGD	~80	575	27.2	32	---

The other factor that we looked at was the amount of Hg absorbed on each of these fly ash samples. We had expected that Hg would be proportional to the unburned carbon percentage in each ash sample. Looking at the first three samples in Table 4, it can be seen that the amount of Hg varied considerably but not in proportion to either the LOI or the surface area of the samples.

The sample with by far the most Hg was taken on 13 September. Calcium bromide was included in the slurry during that test. The high Hg content of this sample can be attributed to the bromine chemistry and the improved carbon effectiveness even though the LOI and surface properties of the total was not improved. The active carbon which did retain Hg, retained 3 to 5 times as much Hg but was overall ½ the LOI; the Bromine making it six to ten times more effective.

This increase in mercury capture across the ESP was achieved with a relatively high ESP operating temperature of 400 to 430°F. This temperature is above the SO₃ dew point of approximately 235°F where most cold-side ESP's are designed to operate. This higher temperature ESP mercury retention would be important:

- whenever SO₃ interferes with active carbon capture of mercury; such as, because of high sulfur coal or high SCR conversion of SO₂ to SO₃, or
- for mercury capture when operating Hot-side ESP, particularly with low chlorine Western Coals.

Conclusions

A series of preliminary tests at Beaver Valley Unit 2 showed that injecting coal cleaning plant waste as a slurry with water (CWS) and other additives shows promise for achieving incremental reductions in NO_x and Hg emissions from coal-fired boilers. Little or no NO_x reduction is achieved when injecting just coal slurry alone into the post-combustion region of the boiler because the onset of unacceptable CO emissions in this furnace and boiler limits the amount of CWS to less than 3 percent of the total heat input. It is possible that more points of CWS injection would distribute the slurry more evenly and allow further NO_x reduction, but the modest improvement would not justify the expense of installing additional injection ports.

However, when urea was added to the CWS, the additional NO_x reduction was significant by enhancing the Selective Non-catalytic Reduction (SNCR) system performance. Though no attempts were made to optimize the slurry injection system for lowest possible NO_x emissions, urea injection with and without CWS showed a 30% reduction when the urea was accompanied by coal. The mechanism for lower NO_x (at injection temperatures above 2100 °F) is thought to be protection of the urea from oxidation by flue gas oxygen. At these temperatures, combustible volatiles released by the coal react preferentially to deplete the flue gas of oxygen that would otherwise have destroyed a portion of the urea before it has a chance to destroy NO_x.

Similarly, mercury emissions were not significantly impacted by the injection of CWS alone. The Hg capture across the electrostatic precipitator averaged about 40%, regardless of the amount or location of the slurry injected. However, the Hg reduction increased to 60% when 1.5 percent CaBr₂ was added to the slurry. This amount translates into about 12 ppmv of bromine in the flue gas.

The results of these brief field trials show promise for incremental improved NO_x and Hg control. However, the reliability of coal slurry injection must be improved before the utility industry will embrace these improvements. The penchant for hoses and injectors to plug when transporting and injecting slurry would be considered unacceptable. Future work needs to focus on this reliability issue. Alternatively, a method to mix the coal and water at the point of injection should achieve the same chemistry without the mess. Pneumatic transport of the damp coal wastes into an annulus with a water injector in the center would be a natural evolution for this technology. Such an injection equipment development would reduce the capital costs of active carbon into the range of current SNCR or dry spray systems and the resultant incremental mercury reduction operating costs might be reduced by one-half without the need for active carbon supply and injection..