Mercury Control for PRB and PRB/Bituminous Blends

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ABSTRACT

On March 15, 2005, EPA issued the Clean Air Mercury Rule, requiring phased-in reductions of mercury emissions from electric power generators. ADA-ES, with support from DOE/NETL and industry partners, is conducting full-scale evaluations to determine the capabilities of activated carbon injection, coal blending, and coal additives for mercury control on different coals and air pollution equipment configurations. This paper will present results from four sites: Sunflower Electric's Holcomb Station, AmerenUE's Meramec Station, Basin Electric Power Cooperative's Laramie River Station, and DTE Energy's Monroe Power Plant.

Holcomb fires a PRB coal and has a spray dryer absorber (SDA) and fabric filter for SO_2 and particulate control. Meramec fires a PRB coal and has a cold-side ESP for particulate control. Laramie River fires a PRB coal and is equipped with an SDA and electrostatic precipitator (ESP). Monroe fires a blend of bituminous and PRB coals and has a selective catalytic reduction process (SCR) for NO_X control and an ESP for particulate capture. Mercury control options tested at these sites included coal blending, coal additives, and treated and untreated activated carbons. The effect of SCR on mercury speciation and mercury removal was also evaluated.

INTRODUCTION

ADA-ES, Inc., is conducting a test program to obtain the necessary information to assess the feasibility and costs of controlling mercury from five plants with configurations that together represent over 80% of the existing coal-fired generation plants and potentially a significant portion of new plants. This program is being conducted under a cooperative agreement with the Department of Energy's National Energy Technology Laboratory (NETL), and is co-funded by EPRI and industry partners. Field testing has been completed at four of the five project sites. Descriptions of these four sites are included in Table 1. The final site scheduled for testing in this program is AEP's Conesville Station, which fires a high sulfur bituminous coal and is configured with an electrostatic precipitator (ESP) and wet scrubber (WFGD). Testing at Conesville is scheduled for spring of 2006.

Table 1. Host Site Key Descriptive Information.

	Holcomb	**Meramec**	**Laramie River**	**Monroe**
	Sunflower Electric	Ameren UE	Missouri Basin Power Project	DTE
Test Period	3/04–8/04	8/04–11/04	2/05–3/05	3/05–6/05
Unit	1	2	3	4
Size (MW)	360	140	550	785
Coal	PRB	PRB	PRB	PRB/Bit blend
Boiler	Opposed-Fired	Tangential-Fired	Wall-Fired	Wall-Fired
Air Preheater	Ljungström Regenerative	Tubular	Ljungström Regenerative	Ljungström Regenerative
NO_x Control	LNB	None	LNB	SCR (May–Sept)
Particulate Control	Fabric Filter	ESP	ESP	ESP
SCA (ft^2/kacfm)	NA	320	599	258
Sulfur Control	Spray Dryer	Compliance Coal	Spray Dryer	Coal Blending
Ash Reuse	Disposal	Sold for concrete	Disposal	Disposal
Test Portion (MWe)	180 and 360	70	140	196
Typical Inlet Mercury (μg/dNm^3)	10–12	10–12	10–12	8–10
Typical Mercury Removal	0–13%	0–30%	<20%	10–35%

BACKGROUND: MERCURY REMOVAL ON SUBBITUMINOUS COALS

Data collected by power producers, EPA, DOE, and EPRI reflect the general trend that native mercury removal at sites firing subbituminous coal (typically PRB) is much lower than at sites firing bituminous coals. This trend is clear in data collected during EPA's 1999 Information Collection Request (ICR) program. The ICR program was initiated to determine current mercury emissions and controls on existing emission control equipment (equipment designed to capture SO_2, NO_x, and particulates). Some of the trends showing that the same emission control equipment at plants burning subbituminous/PRB coals captured lower amounts of mercury than plants burning bituminous coals can be seen in Table 2 (Sjostrom et al., 2002).

Table 2. ICR Data Comparing Native Mercury Removal Efficiencies between Bituminous and Subbituminous Coals.

Controls	**Average Removal Efficiency**	
	Bituminous	**Subbituminous (PRB)**
Cold-Side Electrostatic Precipitator (ESP)	46%	16%
Fabric Filter (FF)	83%	72%
Spray Dryer Absorber (SDA) and FF	98%	25%

Aside from the difference in heating value between bituminous and PRB coal, there are obvious differences in the sulfur and chlorine concentrations with the PRB coals lower in both. Studies conducted by URS Group, UNDEERC, and others over the past 15 years indicate that HCl and sulfur in the flue gas can significantly impact the adsorption capacity of fly ash and activated carbon for mercury (CEA, 2005; Carey et al., 1998). In general, results from laboratory studies suggest:

- HCl and H_2SO_4 accumulate on the surface of carbon.
- HCl increases the mercury removal effectiveness of activated carbon and fly ash for mercury, particularly as the flue gas HCl concentration increases from 1 ppm to nominally 10 ppm. The relative enhancement in mercury removal performance is not as great above 10 ppm HCl. In the absence of HCl, the ability of carbon to remove elemental mercury is minimal. Other strong Brønsted acids such as the hydrogen halides HCl, HBr, or HI should have a similar effect. Halogens such as Cl_2 and Br_2 should also be effective at enhancing mercury removal effectiveness, but this may be a result of the halogens reacting directly with mercury rather than the halides promoting the effectiveness of the activated carbon.
- SO_2 reduces the equilibrium capacity of activated carbon and fly ash for mercury. Activated carbon catalyzes SO_2 to H_2SO_4 in flue gas. Because the concentration of SO_2 is much higher than mercury in flue gas, the overall adsorption capacity is likely dependant on the SO_2 concentration in the gas as it forms H_2SO_4 on the surface of the carbon. Thus, the capacity of activated carbon for mercury is higher in low SO_2 flue gas.

PRB coal typically contains <1% sulfur and <50 ppm chlorine, and the mercury is primarily in the elemental form. Activated carbon sorbents and high surface area unburned (loss on ignition, or LOI) carbon should be very effective for mercury capture when sufficient halogens or halides are present in the flue gas.

In 2001, sorbent-based mercury control technology was first applied to full-scale plants burning PRB coals. In general, mercury removal for units configured with ESPs was limited to roughly 70% (Durham, et al., 2002). This limitation likely represented the point where available HCl was removed from the gas stream by injected carbon. Excess carbon did not result in additional removal because insufficient HCl was available to promote oxidation and chemisorption of the elemental mercury. Variations from site to site should be influenced by variations in the SO_2 and HCl in the flue gases. Data were also available from a site firing North Dakota lignite coal (low sulfur, low chlorine) configured with an SDA and FF. These results indicated that the mercury removal achievable was much lower than would be expected on a unit without a spray dryer (Sjostrom, et al., 2002; Bustard et al., 2003; Machalek, et al., 2004). Although the spray dryer reduces the SO_2 concentration, insufficient HCl remained in the gas at the fabric filter to allow high mercury removal.

RESULTS

This test program was designed to provide a full-scale evaluation of technologies that can overcome the limited mercury removal achievable at sites firing PRB coal. Each technology was based on increasing the available chlorine or bromine in the flue gas when necessary and supplementing with activated carbon to achieve high (>80%) mercury removal. Three technologies were evaluated. These technologies and the effect on mercury removal were:

1. **Coal Blending**: By blending higher chlorine western bituminous coal with PRB coal, the mercury removal across the SDA + FF at Holcomb increased from <10% to almost 80% without injecting activated carbon. No improvement was noted while blending with low chlorine western bituminous coals at Laramie River Station.
2. **Bromine-Treated Activated Carbon**: NORIT Americas' DARCO® Hg-LH produced mercury removal in excess of 90% at Holcomb, Laramie River, and Meramec. No improvement was noted at Monroe, which typically fires 40% eastern bituminous coal with the balance PRB.
3. **Chemical Addition to the Coal with Activated Carbon**: KNX, a proprietary halogen-based chemical developed by ALSTOM Power, was found to enhance the performance of a standard activated carbon at Holcomb, Laramie River, and both unburned carbon and activated carbon at Meramec.

The results indicate that sites firing PRB coal provide favorable flue gas conditions for high mercury removal with unburned carbon and activated carbon when halogens or halides are added to the flue gas using the techniques listed above.

Coal Blending

One option for improving mercury capture at sites firing PRB coal is blending with a coal that contains higher chlorine or bromine to increase the flue gas halogen or halide concentration. Although western bituminous coals typically contain less chlorine than eastern bituminous coals, some have significantly higher chlorine concentrations than found in PRB coals. As an added benefit, the western bituminous coals are typically low in sulfur, which should be beneficial for mercury removal. Western bituminous coals from three mines were tested during this program. Coal halide and sulfur concentrations for the western bituminous and PRB coals fired during coal blending tests are shown in Table 3.

Table 3. Western Bituminous Coal Mercury, Halide, and Sulfur.

Coal	Hg (µg/g)	Cl (µg/g)	F (µg/g)	Br (µg/g)	S (%)
Jacobs Ranch (PRB)	0.105	9	76	1.8	0.56
Black Thunder (PRB)	0.077	8	80	0.6	0.32
Caballo Rojo (PRB)	0.070	8	NA	NA	0.39
West Elk (W. Bit)	0.103	106	84	1.4	0.93
Colowyo (W. Bit)	0.093	11	NA	NA	0.37
LRS Coal #2 (W. Bit)	0.047	15	NA	NA	0.54

One week of coal blending tests was conducted at Holcomb. The baseline PRB coal was from the Jacobs Ranch mine. During blending tests, PRB coal from the Black Thunder mine was co-fired with western bituminous coal from the West Elk mine. Two different blend ratios of Black Thunder and West Elk were evaluated. The vapor-phase mercury removal during the first blend test was an average of 50% compared to no removal with 100% Jacobs Ranch PRB during this test period. The removal across the SDA-FF during the second blend test increased to 76%. These results are summarized in Figure 1.

Results from EPA M26A measurements at Holcomb indicate that the SDA and fabric filter combination is fairly effective at removing HCl. More than 40% of the HCl was removed in the SDA and a total of nominally 80% was removed across the SDA and FF combined. During coal blending tests, the chlorine concentration in the blended coal was doubled with 7% western bituminous and tripled with 14% western bituminous in the blend. Most of the chlorine present in the coal should exist as HCl downstream of the air preheater. Thus, at the inlet to the fabric filter at Holcomb after 40% of the HCl is removed in the SDA, the HCl concentration during blend tests should be similar to inlet HCl concentrations at sites without SDAs. The ICR results indicate that the average mercury removal across units firing PRB coal with fabric filters (no SDA) is 72% (see Table 2), which is roughly the same as that achieved at Holcomb. Therefore, the results can be attributed to the higher chlorine concentration in the West Elk coal.

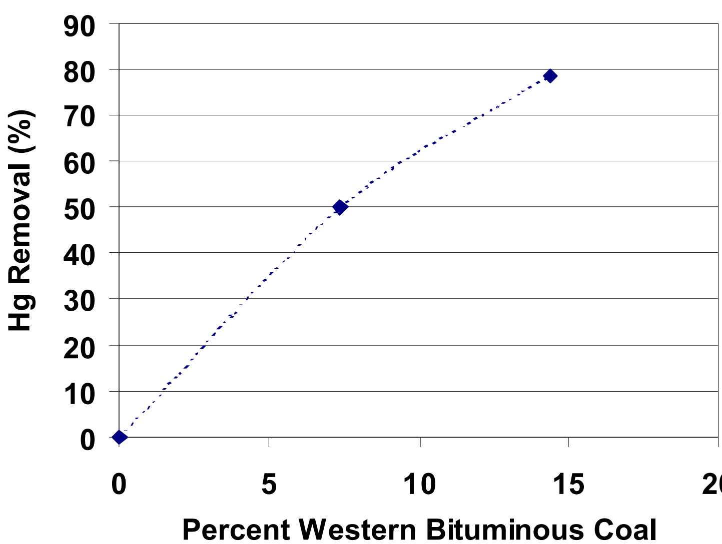


Figure 1. Summary of Coal Blending Tests Conducted at Sunflower Electric's Holcomb Station, 2004.

Coal blending tests were also conducted at Laramie River Station. Results from these tests indicated that little or no improvement in the native mercury removal across the system was achievable at up to 20% western bituminous coal. The mercury speciation at the inlet to the SDA and outlet of the ESP were also consistent with baseline measurements, indicating that the addition of the western bituminous coal had no effect on the mercury. A slight improvement in the mercury removal, from 12% during baseline testing to 18% during blend testing, was noted with the second western bituminous coal (blend 84% PRB, 16% western bituminous).

Because Laramie River Unit 3 is configured with an SDA and ESP rather than an FF, the effect of coal blending on mercury removal was expected to be lower than at Holcomb. Additionally, the chlorine concentration in the western bituminous coals tested at Laramie River was only slightly higher than the chlorine concentration in the Caballo Rojo PRB coal (11 and 15 ppm for the western bituminous coals, 8 ppm for the PRB coal, as shown in Table 3). The similarity in the chlorine concentrations in the western bituminous and PRB coals tested at Laramie River could account for the minimal influence of coal blending on mercury removal observed at Laramie River.

Baseline mercury removal at Monroe ranged from 7 to 35% at a blend ratio of 60% PRB and 40% eastern bituminous coal. No change in mercury removal was noted by decreasing the bituminous fraction to 30%. The fraction of oxidized mercury changed from 52% at the higher blend to 37% at the lower blend.

Coal Additives

Another option for introducing halogens or halides to the flue gas is by adding them to the coal. The additive tested at Holcomb, Laramie River, and Meramec was KNX, a proprietary ALSTOM Power product. KNX was applied to the coal prior to the coal bunkers at Holcomb and Meramec and at the coal feeder at Laramie River.

No change in the mercury removal was noted at either SDA site (Laramie River or Holcomb) as a result of KNX injection. The KNX alone resulted in high mercury removal at Meramec. Three key differences at Meramec compared to Holcomb and Laramie River that may have contributed to the differing results were 1) Meramec is not configured with an SDA, 2) the LOI carbon was higher at Meramec, and 3) there is a long residence time through the tubular air preheater and long ESP inlet ductwork at Meramec.

With KNX, vapor-phase removal across the ESP at Meramec ranged from 57 to 64%, compared to 22 to 34% with no KNX. With KNX injection, the ash adsorbed mercury prior to the inlet SCEM location. Thus the total mercury removal, based on input from the coal and SCEM measurements at the outlet, was 88% with KNX testing compared to <40% total mercury removal without KNX. The fraction of unburned carbon in the fly ash during the KNX test period ranged from 0.4 to 3.8, with an average of 1.8% during the week of testing. The LOI carbon content is typically <1% in PRB coals. Although these data suggest the KNX alone can enhance the effectiveness of native fly ash containing unburned carbon, especially when a long residence time is available, results from Holcomb and Laramie River suggest that high mercury removal may not be achievable at most sites firing PRB coal with typical unburned carbon levels and system residence times. However, the SDA may have also contributed to the poor removal at Holcomb and Laramie by removing halogens or halides prior to the particulate collector.

It is interesting to note that increasing the halide content in the flue gas through coal blending was successful at Holcomb, but introducing halogen to the coal with additives had no effect on mercury removal. Two possible explanations include 1) other elements in the coal used in the blend contributed to the positive results, or 2) the type of coal additive used formed a halogen or halide product that was effectively removed in the SDA and not present at the fabric surface (compared to coal blending, where sufficient chlorine was still available at the fabric surface).

Results from all three sites indicated that the fraction of oxidized mercury at the inlet location increased during KNX addition. At Meramec, both the fraction of oxidized mercury and the fraction of particulate mercury increased (>50% particulate-phase mercury during KNX injection). It is possible that the higher fraction of particulate mercury at the inlet to the ESP at Meramec was influenced by both the relatively high fraction of unburned carbon present in the fly ash and the long residence time before the ESP. At both SDA sites (Holcomb and Laramie River), the fraction of oxidized mercury at the outlet of the system was only slightly higher during KNX injection than during baseline testing and no change in the mercury removal was noted. This suggests that either the KNX addition resulted in a sampling artifact that biased the elemental mercury measurement by the mercury monitor, or the SDA was reducing oxidized mercury back to the elemental form.

Activated Carbon Injection

"Standard" Activated Carbon

DARCO® Hg is a lignite activated carbon that does not have additional chemical treatment to enhance effectiveness for mercury removal. The vapor-phase mercury removal efficiency of DARCO® Hg at the two ESP sites firing 100% PRB coal was limited. The maximum mercury removal achieved at Meramec was limited to 75% while injecting DARCO® Hg at injection concentrations >5 lb/MMacf. The maximum mercury removal achieved at Laramie River was 52% at 6 lb/MMacf. These data are presented in Figure 2. The maximum removal at Laramie River may have been lower because HCl was removed in the SDA at Laramie River. The limited mercury removal at Meramec and Laramie River indicates that activated carbon injection concentrations of 3 to 10 lb/MMacf are sufficient to absorb the available halides at these sites so that subsequent increases in sorbent injection concentrations are ineffective for increased mercury capture. Limited mercury removal has been observed using DARCO® Hg at several other sites firing 100% low-rank coals (PRB or North Dakota lignite) and configured with ESPs (Durham et al., 2002; Starns et al., 2004).

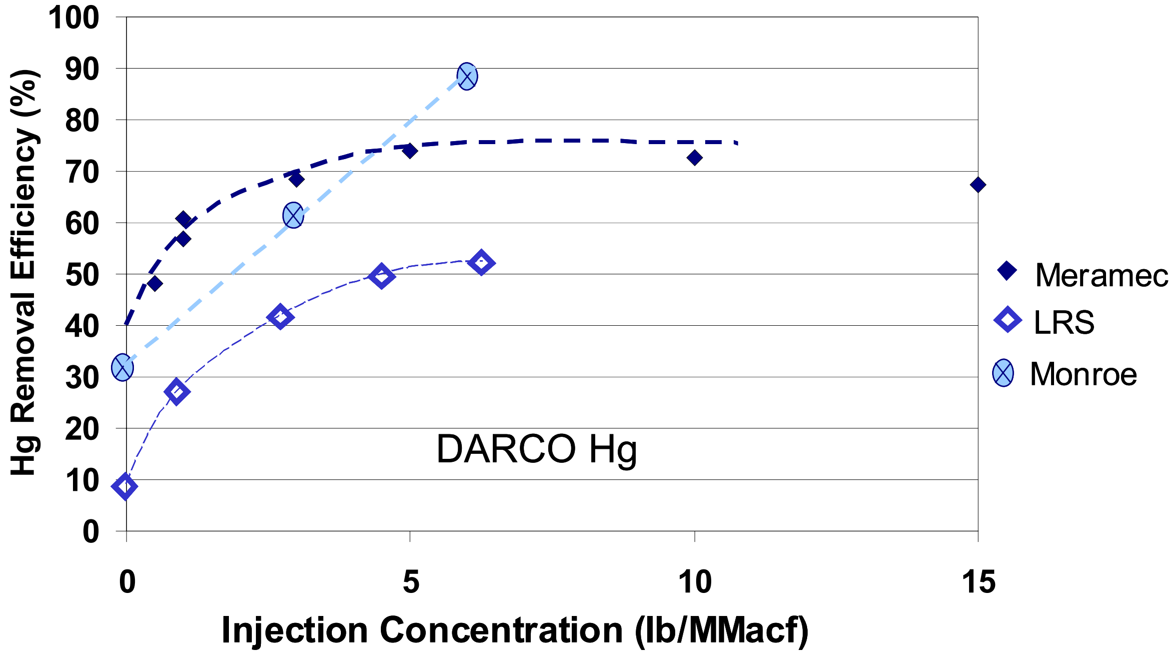


Figure 2. Summary of DARCO® Hg Results at Meramec, Laramie River, and Monroe.

The coal at Monroe Power Plant is a blend of PRB and bituminous coals (typically 60% PRB and 40% bituminous). The addition of bituminous coal results in higher HCl and SO_2 concentrations in the flue gas than at sites firing 100% PRB coal. Results from DARCO® Hg testing at Monroe indicate lower initial mercury removal, but the removal continued to improve with increasing activated carbon, suggesting that sufficient halides were available for continued effectiveness of the activated carbon. The data from Laramie River, Meramec, and Monroe are presented in Figure 2. The data suggest that the mercury removal at low injection concentrations may be lower at Monroe than at Meramec. This may be a result of the higher SO_2 concentrations in the flue gas at Monroe. At high injection concentrations, Meramec had reached the maximum achievable removal while the removal at Monroe continued to increase.

Two "virgin" activated carbons were evaluated with the SDA and FF at Holcomb: DARCO® Hg and Calgon's 208CP. Results indicated that the mercury removal efficiency of these two materials was similar: 50–54% mercury removal was achieved at an injection concentration of 1.0 lb/MMacf. These data are presented in Figure 3.

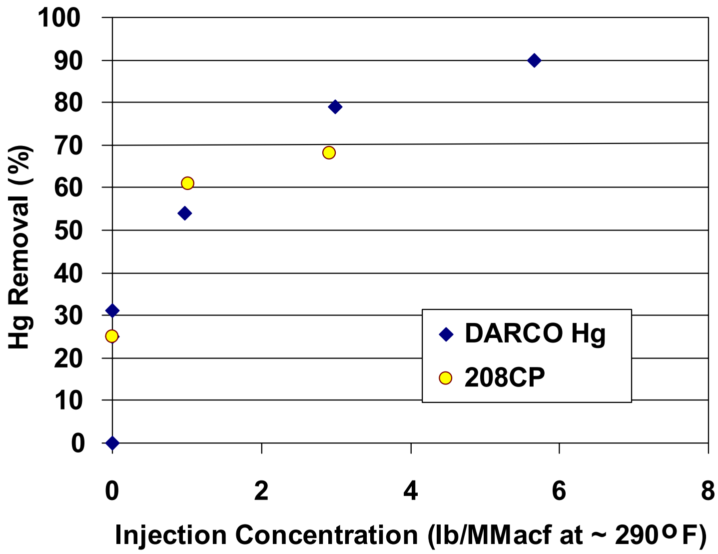


Figure 3. Mercury Removal Effectiveness of Activated Carbon at Holcomb.

"Standard" Activated Carbon with Coal Additives

During testing at Holcomb, Laramie River, and Meramec, DARCO® Hg was injected while treating the coal with KNX to determine whether adding halogen to the coal was an effective method to increase the mercury removal with non-chemically treated activated carbon. The results from these sites are summarized in Table 4. As shown, the KNX was effective at increasing the mercury removal of activated carbon at all sites.

Table 4. Mercury Removal With and Without KNX.

Site	DARCO® Hg Concentration	Hg Removal with KNX	Hg Removal Without KNX
Holcomb	1.1 lb/MMacf	86%	54%
Laramie River	4.5 lb/MMacf	94%	50%
Meramec	5 lb/MMacf	88% *(97% total removal)**	73%

* *Total removal (coal to outlet) at Meramec is higher due to high particulate fraction of mercury at inlet SCEM location during KNX injection.*

Bromine-Treated Activated Carbon

An alternative method of enhancing the effectiveness of activated carbon is treating the carbon with halides prior to injection. NORIT's product, DARCO® Hg-LH, is a bromine-treated version of DARCO® Hg and is designed for low halogen or halide environments. DARCO® Hg-LH was tested at all sites during this program.

Results from the ESP sites firing 100% PRB coal, Laramie River and Meramec, indicate that DARCO® Hg-LH was much more effective at mercury capture than the non-bromine-treated version. These data are summarized in Figure 4. The results also suggest that there is no significant difference in the mercury removal obtained with activated carbon injection whether the halogen is introduced into the boiler with the coal or by pretreating the activated carbon with halogen prior to injection.

When halides or halogens are present in sufficient quantities, such as occurred at Monroe, no improvement was noted when using DARCO® Hg-LH, as shown in Figure 5. Monroe typically fires a blend of 60% PRB and 40% eastern bituminous coal. This suggests that the halogen or halide concentration in the gas was high enough that introducing additional halogen with the activated carbon was unnecessary. Based on EPA M26A tests, the HCl concentration at Monroe was 46 to 67 ppm, compared to 0.6 to 0.9 ppm at Meramec. HCl measurements were not conducted at Laramie River, but the level at Holcomb at the inlet to the SDA was 0.13 to 0.61 ppm, which should be similar to Laramie River because the coal chloride levels were similar.

The data from Monroe also indicate there was no effect on mercury removal with DARCO® Hg whether the SCR was bypassed or in-service.

Figure 4. Comparison of DARCO® Hg and DARCO® Hg-LH at Laramie River and Meramec.

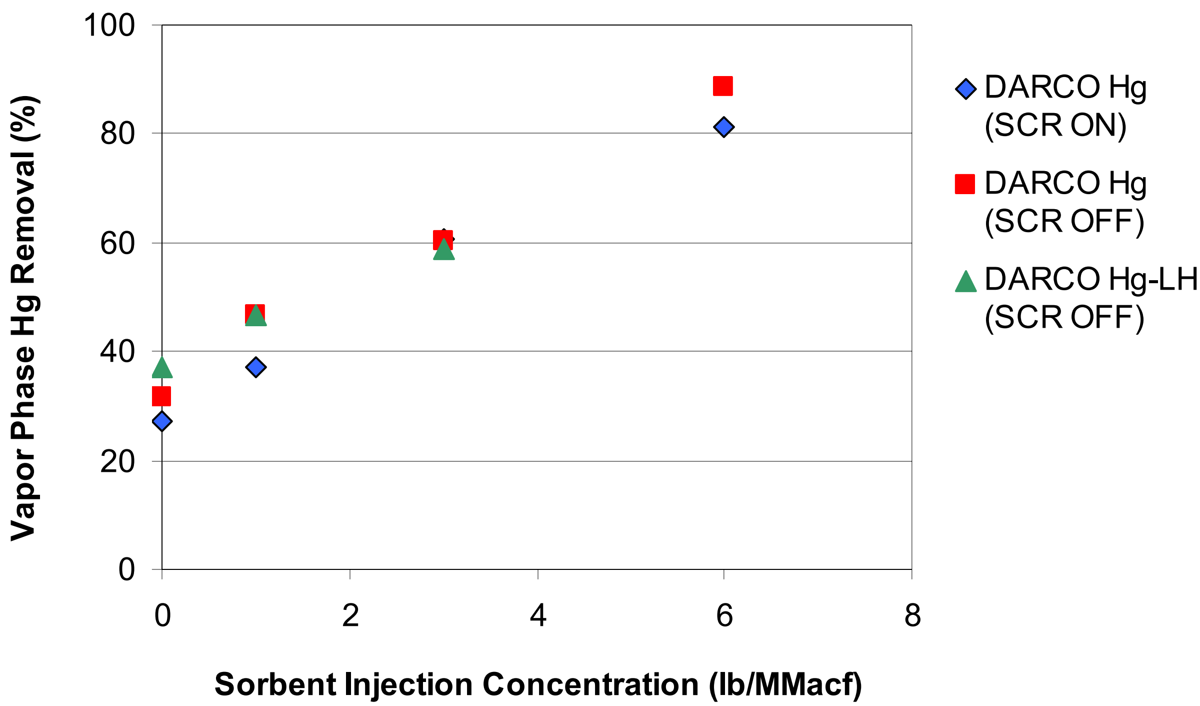
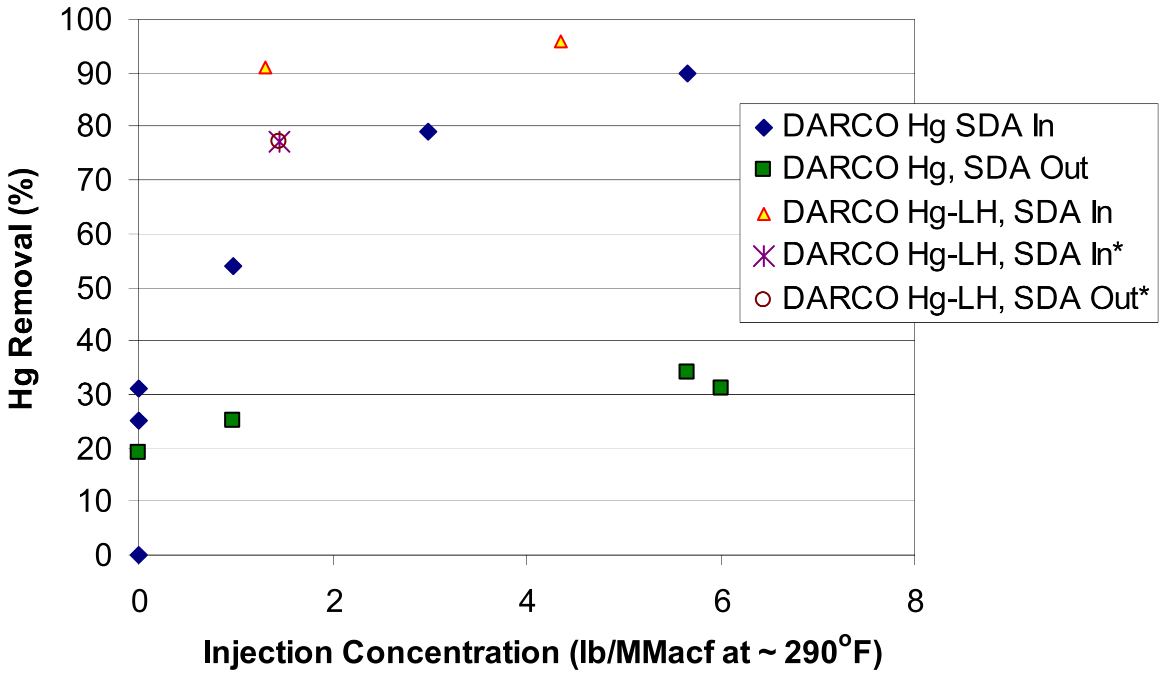


Figure 5. Comparison of DARCO® Hg and DARCO® Hg-LH—Preliminary Results from Monroe Power Plant.

Another indicator of the importance of halogens can be seen when comparing the performance of DARCO® Hg and DARCO® Hg-LH injected upstream and downstream of the SDA. Ninety percent mercury removal was achieved with DARCO® Hg at an injection concentration of 5.7 lb/MMacf upstream of the SDA at Holcomb. The mercury removal was limited to less than 35% when DARCO® Hg was injected downstream of the SDA at injection concentrations up to 5.7 lb/MMacf. The injection concentrations indicated above are both calculated at the SDA inlet temperature for comparison purposes. For comparison, there was no difference in the performance of DARCO® Hg-LH whether injected upstream or downstream of the SDA. This suggests that the difference in the performance observed with DARCO® Hg was due to a change in the halogen level in the sorbent and not due to other factors such as residence time in the SDA. These data are also included in Figure 6.



** Short (<2 hour) results.*

Figure 6. Results of Injection Location Tests, Holcomb Station.

DARCO® Hg-LH was evaluated at Holcomb and Meramec during 30-day continuous injection periods. DARCO® Hg-LH was not required at Monroe. It is likely that sufficient halogens were available from the bituminous coal in the blend at Monroe and that any additional halogens introduced with the activated carbon were unnecessary. The average mercury removal and emissions for the tree sites is shown in Table 5. A trend graph of mercury emissions and DARCO® Hg injection concentration for the tests at Monroe is presented in Figure 7. No balance-of-plant problems, such as increased opacity or changes in the SDA, FF, or ESP operation, were noted at any of the sites as a result of activated carbon injection.

Table 5. Summary of 30-Day Continuous Injection Results.

Site	Configuration	Coal	Sorbent	Removal (%)	Emissions (lb/TBtu)	Injection Concentration (lb/MMacf)
Holcomb	SDA + FF	100% PRB	DARCO® Hg-LH	93	0.8	1.2
Meramec	ESP	100% PRB	DARCO® Hg-LH	93	0.44	3.3
Monroe	SCR, ESP	60/40 PRB/Bit (typ)	DARCO® Hg	78	0.84	4.9

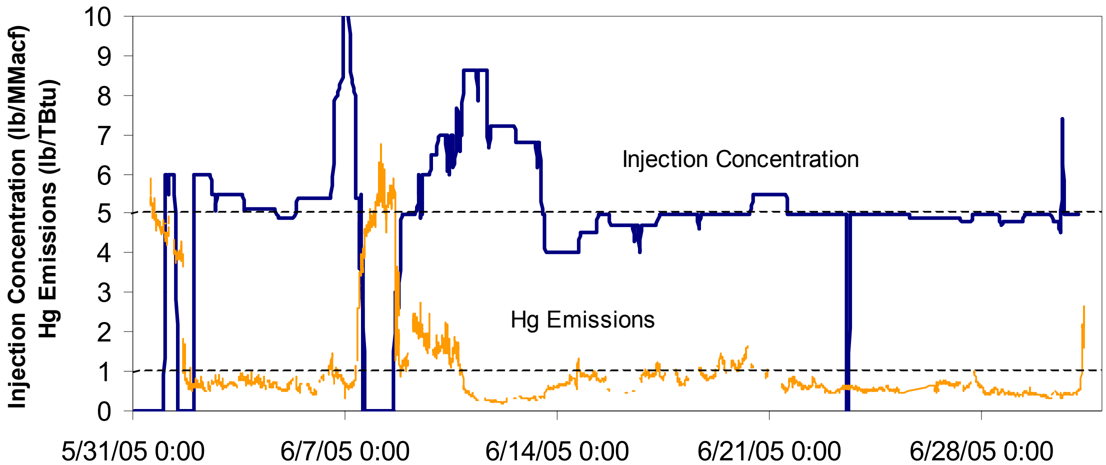


Figure 7. 30-Day DARCO® Hg Injection Test Results from Monroe.

Sorbent Cost Analysis

A comparison of the sorbent costs for Holcomb, Meramec, and Monroe are shown in Figure 7. The economic analysis indicates that the lowest cost option is Holcomb (SDA + FF, PRB, DARCO® Hg-LH) followed by Meramec (ESP, PRB, DARCO® Hg-LH). The costs for Monroe are higher than Meramec and it is believed that this is a result of the higher sulfur in the coal at Monroe. Sorbent cost estimates for two other sites—Brayton Point (ESP Bit, DARCO® Hg) and Abbott (ESP, HS Bit, DARCO® Hg)—are included to illustrate the increased cost with coal sulfur, which was tested during an EPRI program. All three bituminous sites contain enough halides that the performance is not expected to improve by using bromine-treated carbon.

It is likely the costs are lowest for Holcomb because Holcomb fires a low sulfur PRB coal and is configured with an SDA, both of which should result in low SO_2 and maximize the effectiveness of activated carbon for mercury capture when using an activated carbon containing sufficient halides.

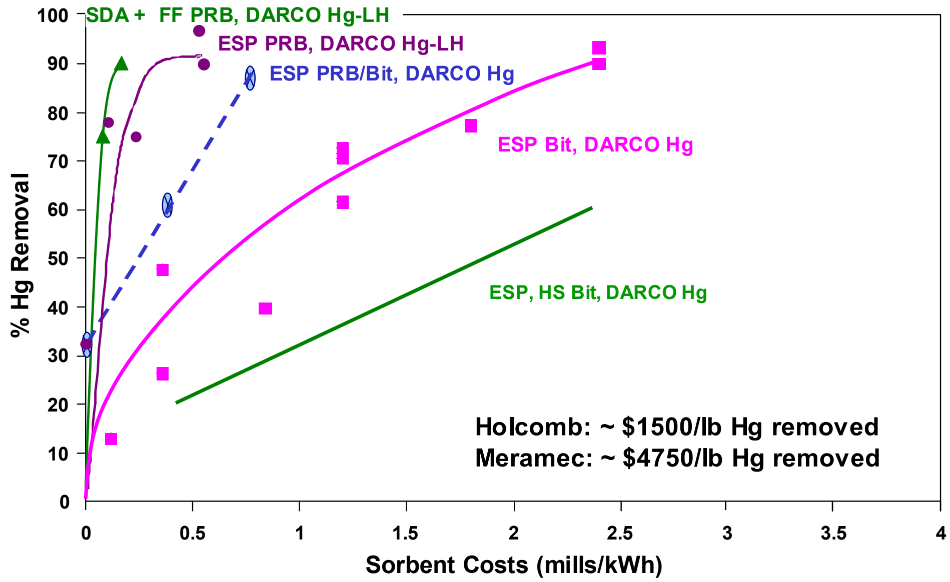


Figure 7. Activate Carbon Cost Comparison for Various Sites.

Because of the higher sulfur levels and corresponding lower mercury removal performance at plants firing bituminous coals, it is expected that this will be a more expensive mercury control configuration for activated carbon injection. Carbon manufacturers are currently developing alternatives for higher sulfur applications. Some of these will be evaluated in this program during testing at AEP's Conesville Station in the spring of 2006.

CONCLUSIONS

Until recently, it was believed that power plants that burn PRB coal represented one of the more challenging applications for controlling mercury emissions. Several new technologies were developed over the past few years and evaluated during this DOE-, EPRI-, and industry-supported program to overcome the limited mercury removal achievable at these sites. Each technology was based on supplementing certain halogens or halides that are not available in sufficient quantities in these coals. Full-scale tests of these new technologies were conducted at four sites. Options evaluated included coal blending, introduction of additives onto the coal, and sorbent injection with chemically treated activated carbons. General conclusions and observations from these tests include:

- **Coal Blending (tested at Holcomb, Laramie River, and Monroe)**
  - Up to 80% mercury removal achieved during short-term western bituminous blend test at Holcomb using West Elk coal, which contained over 10 times more chlorine than the PRB coal fired during testing. According to data collected during EPA's ICR program, the average mercury removal at sites that fire PRB coal and have fabric filters and no SDA is 73%, indicating the blended coal at Holcomb effectively removed the negative impact of the SDA on mercury removal.
  - Little mercury removal noted at Laramie River up to 20% western bituminous coal. Two coals were tested at Laramie River and the chlorine concentration of each was similar to the PRB blend coal.
  - Baseline removal at Monroe ranged from 7 to 35% (60/40 blend PRB/bituminous). According to data collected during EPA's ICR program, the average mercury removal at sites with ESPs that fire bituminous coal is 46%.
- **Coal Additives (KNX tested at Holcomb, Laramie River, and Meramec)**
  - Greater than 80% removal achieved at Meramec in the presence of unburned carbon but without additional activated carbon. *(The baseline removal during this period was estimated to be >30%. Plant configuration and high LOI may have contributed to removal with KNX.)*
  - Additives alone were not effective at Holcomb and Laramie River and it was necessary to combine the additives with activated carbon to achieve high removal. *This is inconsistent with the coal blending results from Holcomb and may be related to differences in halogens in the KNX compared to the western bituminous coal, the removal efficiency of the SDA for the halogen or halides formed, or unidentified properties of the western bituminous coal.*
- **Treated Activated Carbon Injection**
  - High removal (>90%) achieved at Holcomb, Meramec, and Laramie River while injecting DARCO® Hg-LH, a bromine-treated activated carbon.
  - DARCO® Hg-LH was not required at Monroe, likely because sufficient halogens were available in the bituminous coal from the blend (60% PRB, 40% bituminous coal).

- Coal additive injection with untreated activated carbon resulted in the same mercury removal performance as treated activated carbon injection.
- No adverse balance-of-plant impacts noted throughout testing.

- **Other Balance-of-Plant Concerns**
  - The mercury captured by activated carbon, LOI carbon, and ash appears to be very stable and unlikely to reenter the environment.
  - Flue-gas bromine measurements were made at Holcomb and Meramec during long-term testing of DARCO® Hg-LH. No levels of bromine in excess of those expected for plants firing PRB coals were measured.
  - Some bromine leaching was observed from ash mixed with treated carbon. The environmental implications are currently being reviewed.
  - Trace amounts of activated carbon can be detrimental to ash quality for cement use. Options to protect ash for sales include TOXECON™ and TOXECON II™. TOXECON II™ tests are scheduled to begin this fall on a separate DOE contract.

ACKNOWLEDGMENTS

This program is possible through the leadership of DOE and many industry partners. Primary funding for this program is through DOE Cooperative Agreement DE-FC26-03NT41986, with significant cost share for testing at Holcomb from industry partners including EPRI, Sunflower Electric Power Corporation, ADA-ES, Arch Coal, Associated Electric Power, Empire District Electric Company, Kansas City Board of Public Utilities (KCKBPU), Kansas City Power and Light, Nebraska Public Power District, Western Fuels Association, Tri-State/Missouri Basin Power Project, Westar Energy, and Wisconsin Public Service. Overall program cost-share partners include EPRI, AmerenUE, AEP, MidAmerican, Southern Company, Dynegy Generation, TVA, Detroit Edison, Ontario Power Generation, Epcor, Babcock & Wilcox, NORIT Americas, ALSTOM, Arch Coal, and ADA-ES.

Special acknowledgments are given to the NETL project manager Mr. Andrew O'Palko and Dr. Ramsay Chang from EPRI, whose guidance was key to the program's success. Mr. Wayne Penrod and Mr. Corey Linville of Sunflower Electric, Mr. Rich Phillips and Mr. Tom Hart of AmerenUE, Mr. Bob Boettcher and Mr. Myron Singleton of Basin Electric, and Mr. Jason Brown and Ms. Melanie McCoy of DTE are also gratefully acknowledged for their support during testing at their facilities.

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