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Accumulated Power-Plant Mercury-Removal Experience with Brominated PAC Injection

Sid Nelson Jr., Ronald Landreth, Ph.D., Qunhui Zhou, Ph.D., and Jon Miller
Sorbent Technologies Corporation, 1664 E. Highland Rd., Twinsburg, OH 44087

ABSTRACT

The injection of brominated powdered activated carbon (B-PAC™) into power-plant flue gases for mercury removal has now been tested at seven different power plants. These plants have burned bituminous, subbituminous, lignite coals, and blends and include testing with cold-side ESPs, hot-side ESPs, spray dryers, and fabric filters. Mercury-removal performance at these sites has varied between 70% and 98% at sorbent consumption costs of approximately $2,000 to $20,000 per-lb-of-mercury-removed, considerably less than previous technologies.

INTRODUCTION

The mercury-removal performance of plain powdered activated carbons (PACs) and iodine-impregnated PACs have proved to be highly variable at power plants, depending on the particular coal burned and the plant's existing air pollution control equipment configuration. So far, however, Sorbent Technologies Corporation's brominated mercury sorbents (B-PAC™) have consistently demonstrated high mercury removal rates at relatively low injection levels across a wide variety of coals and configurations. See Table 1 below.

Table 1. B-PAC results to date indicate applicability across all coals and plant configurations

Coal	PM Unit	Hg Removal	@lb/MMacf	@ Plant	Scale	Data
Bitum. Low-S	FF	**94%**	**0.5**	Valley	Slipstream	Apogee
Bitum. High-S	CS-ESP	**70%**	**4.0**	Lausche	Full-Scale	SorbTech
Bitum. Low-S	HS ESP	**>80%***	**6.4**	Cliffside	Full-Scale	SorbTech
Subbitum.Blend	CS-ESP	**90%**	**3.0**	St. Clair	Full-Scale	SorbTech
Subbituminous	CS-ESP	**90+%**	**3.0**	St. Clair	Full-Scale	SorbTech
Subbituminous	CS-ESP	**89%**	**4.9**	Pleasant Prairie	Slipstream	Apogee
Subbituminous	FF	**87%**	**0.5**	Pleasant Prairie	Slipstream	Apogee
Subbituminous	SD/FF	**82%****	**<1.8**	Holcomb	Slipstream	ADA-ES
Lignite	SD/FF	**95%**	**1.5**	Stanton 10	Full-Scale	EERC
Lignite	CS-ESP+	**70%*****	**1.5**	Stanton 10	Full-Scale	EERC

* when under low-load conditions. STC will return in the fall for additional runs.
** on-fabric removal only, with no in-flight opportunity and the effective "injection rate" could have been significantly lower.
*** actually the in-flight Hg removal across the spray dryer, with an injection rate of only 1.5 lb/MMacf.

This paper will summarize the B-PAC injection performance that has been observed by Sorbent Technologies Corporation and other companies on actual coal-fired flue gases to date. Note that the mercury emission reduction data and costs presented here count only sorbent-injection-related reductions and not any additional reductions due to native mercury removal already achieved at the sites or to possible non-control-related reduction strategies.[1]

SLIPSTREAM RESULTS

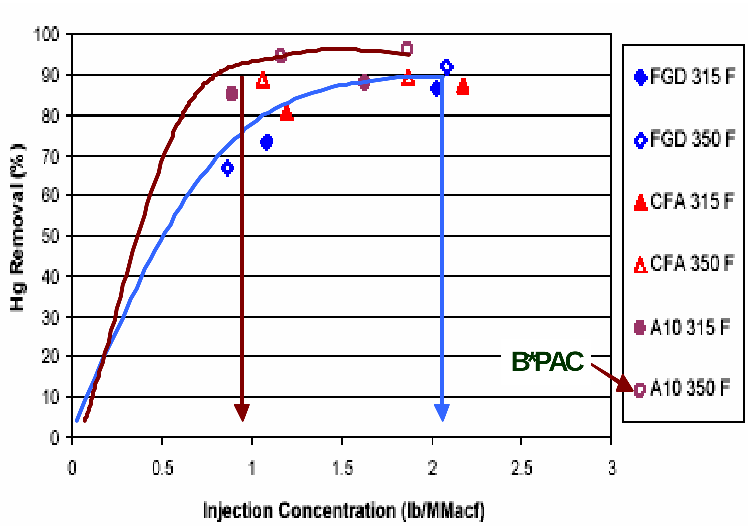
Because the chemical composition of coal-fired flue gases is complex and site-specific, it is important to test new mercury control technology on many different actual coal-fired gas streams to determine general applicability. Apogee Scientific, Inc. has used two EPRI-owned Pollution Control Test (PoCT) modules to test sorbent injection with a variety of sorbents at a number of different power plants. These units extract particulate-free flue gas from after a unit's ESP or fabric filter and then inject the sorbent into the slipstream for measurements of their mercury removal abilities. One PoCT module has a fabric element to simulate operation with a baghouse and a second module is simply an open "residence-time" chamber to simulate the in-flight mercury removal observed with an ESP. Details on the units have been published elsewhere.[2] Good correlations with full-scale results have been shown. Sorbent Technologies' B-PAC materials have been tested by Apogee in three coal type/equipment configuration trials.

Bituminous Coal & Fabric Filter: We Energies' Valley Station

If a power plant has a fabric filter, either by itself, with a spray dryer, or as an added Toxecon I® system, mercury sorbent injection can be very efficient. Because of the long and intimate exposure of the flue gas to the sorbent in the filter cake, sorbent consumption can be very low.

For fabric filters, B-PAC was tested on a low-sulfur bituminous slipstream at We Energies' Valley Plant by Apogee with the PoCT fabric filter simulator. B-PAC performed the best of the various sorbents tested, achieving 94% removal with a consumption rate of a little over 1.0 lb-per-million-actual-cubic-feet-of-flue-gas (MMacf).[3] Standard PACs required injection rates of 1.5 to 2.0 lb/MMacf to achieve 90% net removal rates under similar conditions. See Figure 1.

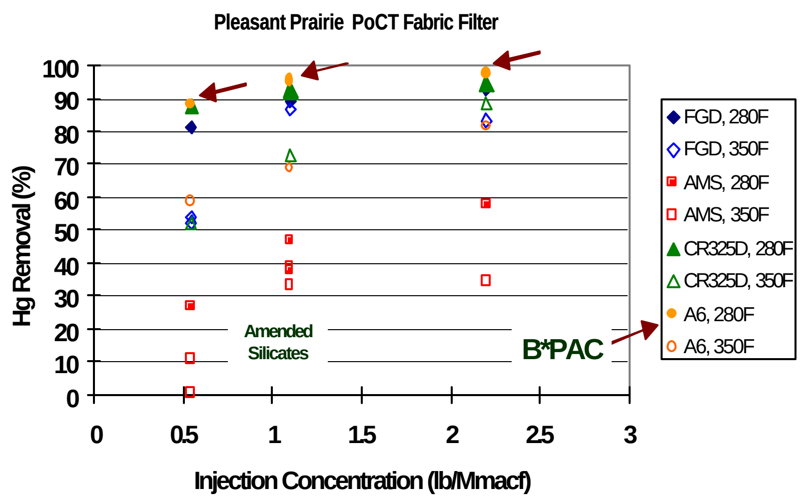
Figure 1. Relative B-PAC performance with a fabric filter.



Subbituminous & Fabric Filter: We Energies' Pleasant Prairie Power Plant

B-PAC was similarly tested by Apogee on a Pleasant Prairie Power Plant subbituminous gas slipstream with the PoCT fabric filter module. Again B-PAC performed the best, with 95% removal at an injection or consumption level of only 1 lb/MMacf. [4]

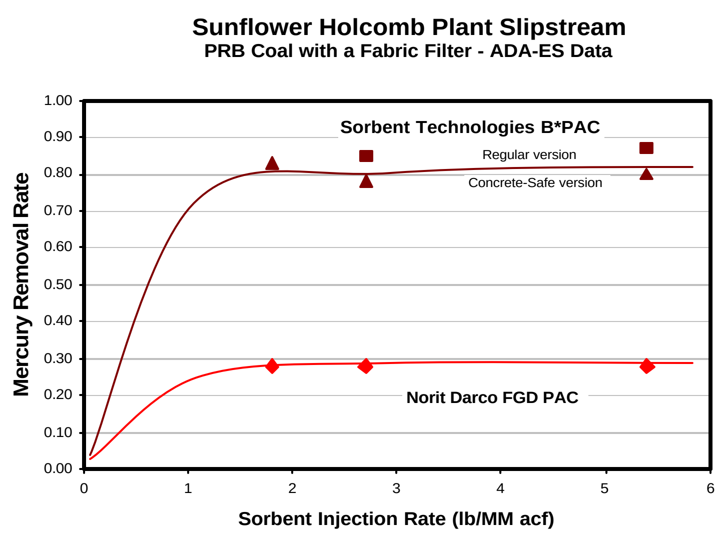
Figure 2. Relative B-PAC consumption and performance with subbituminous coal.



Subbituminous & Spray Dryer/Fabric Filter: Sunflower's Holcomb Station

Two versions of B-PAC were also tested by ADA-ES in a similar, though static, arrangement on a low-Cl slipstream from after the spray dryer at Sunflower Electric Power's Holcomb Station. Again the B-PAC performed admirably. While the mercury removal performance of the plain PAC leveled off at 30%, probably due to the absence of HCl removed by the spray dryer, both the regular and "concrete-friendly™" versions of B-PAC achieved over 80% removal. (Note that there may have been some short-circuiting of the sorbent-and-fly-ash beds as the test procedure did not actually inject the sorbent, but was placed on cloth pre-mixed with fly ash.)

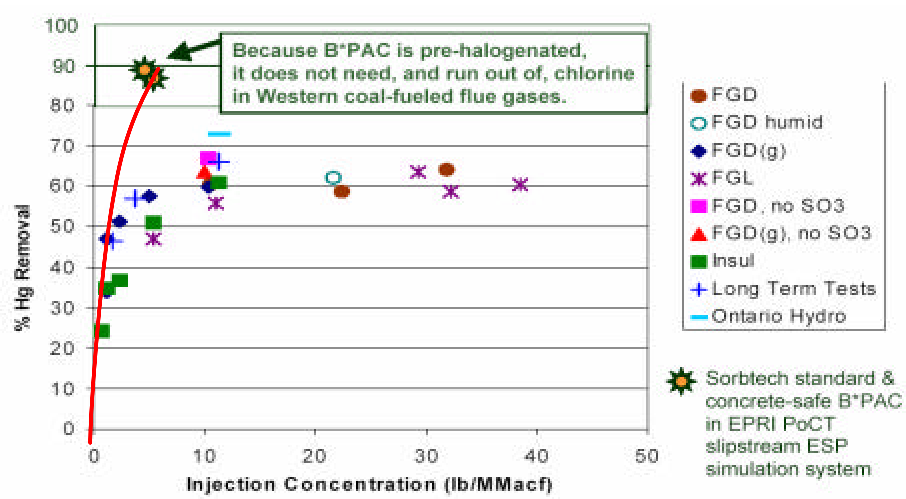
Figure 3. Relative performance of B-PAC and plain PAC at the Holcomb Station.



Subbituminous & Cold-Side ESP: We Energies' Pleasant Prairie Power Plant

Standard B-PAC and a special "concrete-friendly™" version were also evaluated by Apogee Scientific for ESP use on a flue-gas slipstream at We Energies' Pleasant Prairie power plant, where DOE supported earlier ADA-ES full-scale ESP testing. Apogee used the "residence-time" module of EPRI's PoCT system, which uses an open chamber to simulate the in-duct flight mercury removal of a sorbent heading to a cold-side electrostatic precipitator (ESP). See the following Apogee B-PAC results with Pleasant Prairie flue gas, superimposed on the prior plain-PAC ADA-ES data. [5]

Figure 4. B-PAC performance with low-chlorine subbituminous coal relative to plain PACs.



B-PAC achieved 90% in-duct mercury removal at Pleasant Prairie and with an injection rate of only 5 to 6 lb/MMacf. If standard B-PAC is sold for about $0.75/lb when produced in high volumes, this calculates out to control costs of only about $7,000/lb of Hg removed, or about 10% of current estimates.

$$\left(\frac{5\,lb\,sorbent}{1{,}000{,}000\,acf}\right)\left(\frac{Nm3}{(90\%)12\,mg\;Hg}\right)\left(\frac{\$0.75}{lb\,sorbent}\right)\left(\frac{1.5\,acf\;@300F}{1\,scf}\right)\left(\frac{35.3scf}{Nm^3}\right)\left(\frac{10^9\,mgHg}{2.2\,lb\;Hg\;removed}\right) = \$7{,}200\,/\,lbHg.$$

(Note that this removal level might be achieved at a somewhat lower injection level in a full-scale installation because of the better mixing at the higher Reynold's numbers of much larger duct diameters and because of sorbent deposits on duct structures that the PoCT system does not have.)

The Pleasant Prairie Power Plant sells all of the its fly ash for use as a cement substitute in concrete. Unfortunately, the tiniest bit of traditional PAC mixed in with the collected fly ash renders it unusable in concrete, where it interferes with special chemicals added to increase aeration of the mix. Fortunately, Sorbent Technologies has developed a "concrete-friendly™" version of B-PAC with dramatically lower aeration interference. [6] This version performed similarly to standard B-PAC in the Apogee mercury tests.

FULL-SCALE RESULTS

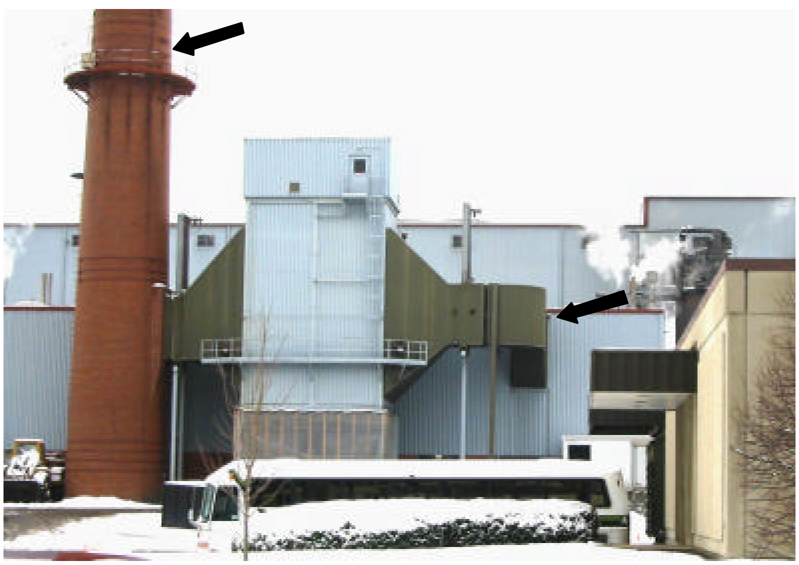
B-PAC injection is now being tested on an increasing number of full-scale coal-fired power plant flue gas streams, all with similar positive results.

Bituminous & Cold-Side ESP: Ohio's Lausche Plant

In January of 2003, Sorbent Technologies field-tested B-PAC variations at the 18-MW scale (60,000 acfm) at the Lausche Plant of Ohio University.[7] This stoker-boiler plant burns high-sulfur bituminous coal and has just a cold-side ESP for pollution control. Baseline Ontario Hydro Method sampling indicated no intrinsic Hg removal.

The mercury measurements were taken by Western Kentucky University (WKU), which has experience at over 15 utility sites with the speciating PS Analytical continuous mercury monitor (CMM) that was primarily relied upon for Hg measurement. Inlet Hg values at Lausche were obtained by sampling upstream of injection. Outlet Hg was measured at the stack. The tested sorbents were injected near the lower arrow in the photo below.

Figure 5 & Table 2. The bituminous coal-fired Lausche Plant ESP and baseline data.



Hg (in µg/Nm³)			
Hg(p)	Hg(+2)	Hg(0)	Hg(T)
0	8-9	1-2	10

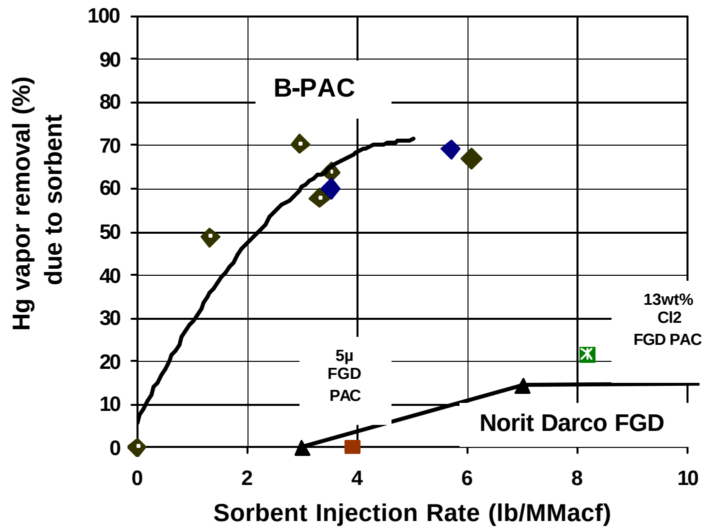
Lausche Plant Injection Conditions	
Scale	18 MW
Gas	60,000 acfm
ESP temp.	320 °F
SO_2	1000 ppm
NOx	250 ppm
HCl	25 ppm
SO_3	20 ppm
SCA	370ft²/Kacfm
Opacity	5%
Resid.time	2.5 Sec

No CFD was performed to optimize sorbent injection. Even though the Lausche plant had a modestly-sized ESP with a specific collection area (SCA) of 370 ft^2/k acfm, B-PAC injection did not cause any measured increase in ESP particulate emissions.

The plain Norit Darco FGD yardstick PAC did not remove much mercury at Lausche. At an injection rate of 18 lb/MMacf, it captured less than 20% of the flue gas mercury. The plant's unusually high SO_3 of about 20 ppm, which competes for the PAC's active adsorption sites, may be responsible for this poor performance.

The B-PAC sorbents, on the other hand, performed very well, achieving about 60% Hg removal at 3 lb/MMacf and about 70% removal at 4 lb/MMacf. See the following test results summary.

Figure 6. Relative B-PAC performance with bituminous coal and an ESP at the Lausche Plant.



$$\left(\frac{4\,lb\ sorbent}{1{,}000{,}000\,acf}\right)\left(\frac{Nm3}{(70\%)\,10mg\ Hg}\right)\left(\frac{\$0.75}{lb\ sorbent}\right)\left(\frac{1.5\ acf\ @\ 300F}{1\,scf}\right)\left(\frac{35.3scf}{Nm^3}\right)\left(\frac{10^9\,mgHg}{2.2\,lb\ Hg\ removed}\right) = \$10{,}300/lbHg.$$

If B-PAC costs $0.75 per lb, the B-PAC mercury removal costs at Lausche translate to only about $10,000 per lb of Hg removed, less than 20% of recent estimates for alternative technologies. STC believes that high-SO_3 sites such as this will be more challenging for mercury control than typical lignite or subbituminous sites.

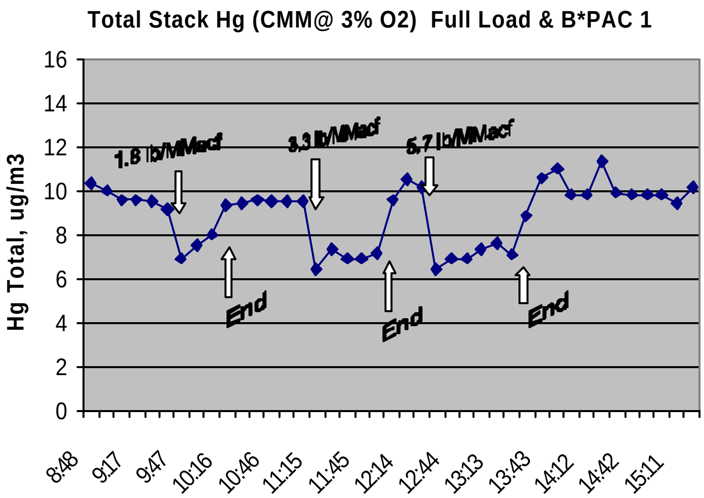
Bituminous & Hot-Side ESP: Duke Energy's Cliffside Station

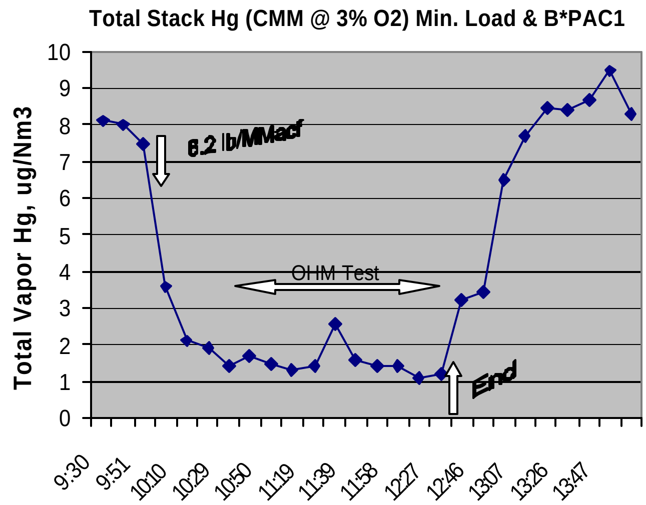
Until now, plants with hot-side ESPs, a substantial subpopulation of U.S. boilers, have had few alternatives for mercury control. They could add expensive secondary fabric filters (Toxecon I) and permanent pressure drop or reconstruct their ductwork and convert to cold-side ESP control.

In September of 2003, as part of qualification testing in its Dept. of Energy B-PAC demonstration program, STC performed the first full-scale mercury sorbent injection trials on a hot-side ESP at Duke Energy's 40 MW Cliffside Plant Unit 2 firing low-S bituminous coal (60-MW-worth of gas @ 700°F).[8] Unlike plain PACs, B-PAC is reactive towards both elemental and oxidized mercury at high temperatures.

The two weeks of Cliffside parametric trials indeed demonstrated mercury reductions at 700^{o}F hot-side temperatures at injection rates similar to those demonstrated at Brayton Point on a cold-side ESP. Under slightly different conditions, over 80% removal was observed with the WKU. CMMs. This performance level was confirmed by Ontario Hydro Method measurements and analyses of the Hg content of the fly ash.

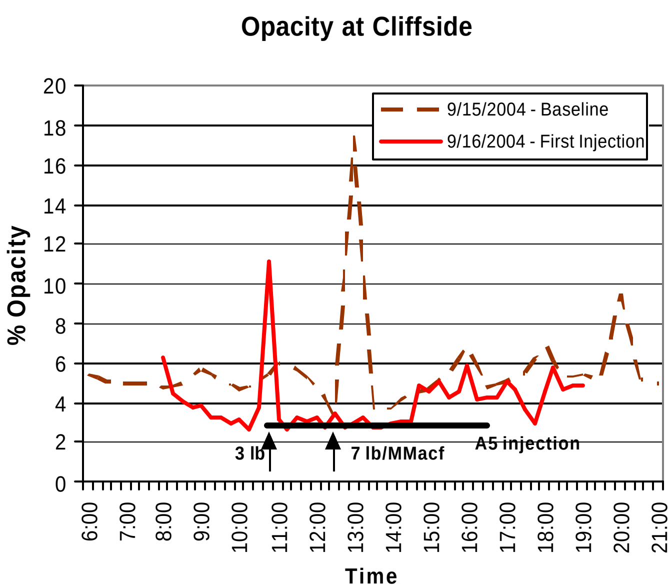
Figures 7 & 8. Stack mercury emission levels at Cliffside with and without B-PAC injection.





As in the earlier Lausche cold-side ESP testing, no degradation of ESP performance was observed in the Cliffside hot-side ESP, which has an SCA of only 240. After blowing ash off of turning vanes when initially turned on, stack opacity was at least as low with B-PAC injection as it was on the previous baseline day. (See the data below on the left.)

Figures 9 & 10. Cliffside opacity with and without sorbent injection and Duke's Buck Plant.



Based on what was learned, STC will go back to Cliffside to try to regularly achieve 90% Hg removal for an extended period of time. Then, in early in 2005, STC is planning larger-scale, parametric and long-term (30-day continuous) testing on the 240-MW (360-MW-equivalent gas @ 700°F) hot-side of Duke Energy's Buck Plant as part of its DOE demonstration program. (See its photo on the right.)

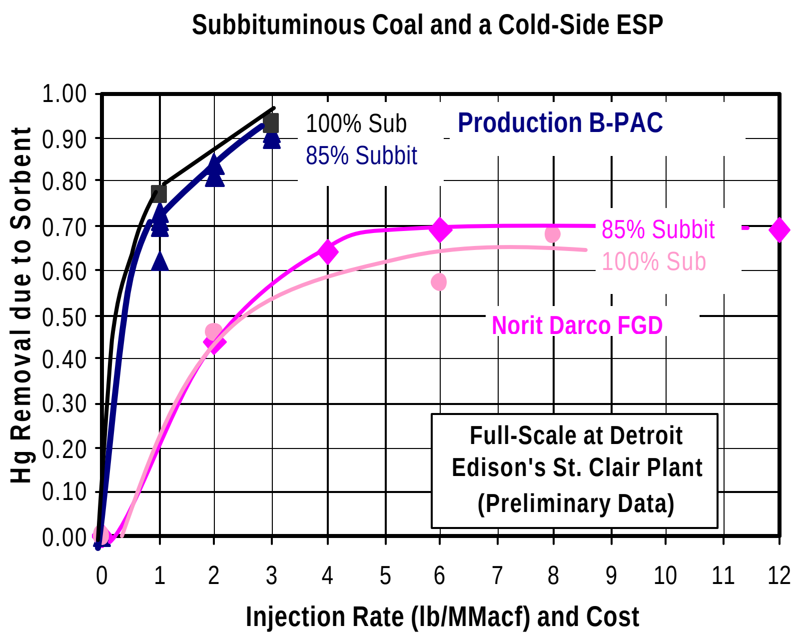
Subbituminous & Cold-Side ESP: Detroit Edison's St. Clair Power Plant

As part of its DOE NETL's project "Advanced Utility Mercury-Sorbent Field-Testing Program," Sorbent Technologies began injecting B-PAC™ at DTE Energy's Detroit Edison St. Clair Station in early August of 2004. The four St. Clair Station 160-MW boilers typically burn a blend of 85% subbituminous coal and 15% Eastern bituminous coal. In this project sorbent is being injected into the ductwork ahead of an 80-MW cold-side ESP. See Figure 11 below. Baseline measurements by WKU using PS Analytical's latest-version CMMs indicate that native mercury removal at the plant varies between 0% and about 40%. Baseline mercury emissions range from about 3 to 8 μg/Nm^3 with about half in the elemental form.

Figure 11. Ductwork leading to the St. Clair ESPs.

B-PAC injection was underway when this paper was written and early, very preliminary data without QA/QC is presented below. For more complete parametric and long-term results, see later papers and reports on the St. Clair trials.[9]

Figure 12. Initial, preliminary data for B-PAC injection at St. Clair.



$$\left(\frac{1\,lb\ sorbent}{1{,}000{,}000\,acf}\right)\left(\frac{Nm3}{(70\%)\,7mg\ Hg}\right)\left(\frac{\$0.75}{lb\ sorbent}\right)\left(\frac{1.5\,acf\ @\,300F}{1\ scf}\right)\left(\frac{35.3scf}{Nm^3}\right)\left(\frac{10^9\,mgHg}{2.2\,lb\ Hg\ removed}\right) = \$3{,}700\,/\,lbHg.$$

The preliminary data from St. Clair suggest that 70% removal due to the B-PAC can be achieved at about $4,000 in sorbent per-lb-Hg-removed and 90% removal for less than $9,000 per-lb.

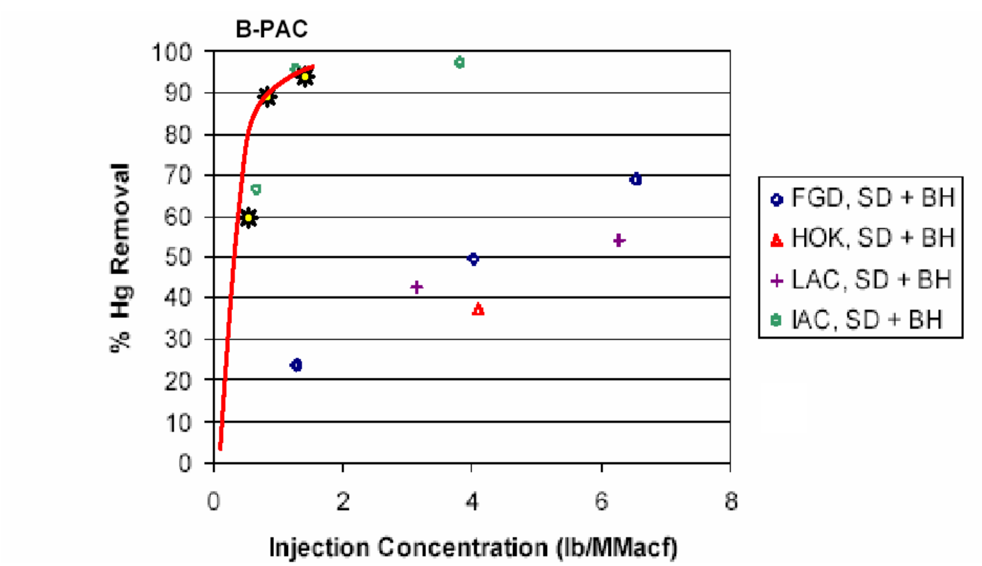
Lignite & Spray Dryer/FF: Great River Energy's Stanton Station 10

Lignite plants are believed by some to be the most difficult for mercury control and in the currently-proposed MACT emission standards were given an allowed emission rate nearly 5 times as high as for bituminous coals.

B-PAC was recently tested at full-scale by Apogee personnel at Great River Energy's lignite-burning Stanton station on a spray dryer/fabric filter system as part of the DOE-NETL/EERC lignite-plant mercury-control demonstrations. Because spray dryers remove the little HCl available in such lignite flue gases, this configuration at Stanton boiler 10 was also previously thought to be especially difficult for mercury control.

The B-PAC results appear below, superimposed on Apogee's prior full-scale data at this site for plain PACs (FGD, HOK and LAC) and iodine-impregnated PAC (IAC).[10] The pre-halogenated iodine carbon (IAC), Barnebey-Sutcliffe's CB 200XF (now part of Calgon), has been reported to cost over $7.00/lb.

Figure 13. B-PAC performance with lignite and a spray dryer/fabric filter system.



$$\left(\frac{1.5lb\ sorbent}{1{,}000{,}000\,acf}\right)\left(\frac{Nm3}{(95\%)\,8.5mg\ Hg}\right)\left(\frac{\$0.75}{lb\ sorbent}\right)\left(\frac{1.5\,acf\ @\,300F}{1\ scf}\right)\left(\frac{35.3scf}{Nm^3}\right)\left(\frac{10^9\,mgHg}{2.2\,lb\ Hg\ removed}\right) = \$3{,}300\,/\,lbHg.$$

At this lignite site B-PAC achieved 95% mercury removal when injected at only 1.5 lb/MMacf.[11] At $0.75/lb, the sorbent consumption at this lignite site would be only $3,300/lb-Hg-removed, not $50,000 to $70,000, as has been estimated for other technologies.[12] Here mercury control with B-PAC costs only about 5% of such estimates, in a supposedly-difficult site situation.

At Stanton 10, the in-flight mercury removal of B-PAC from its injection point to before the fabric filter was also measured. This roughly approximates the mercury removal that might be observed with lignite and a cold-side ESP, though perhaps with more residence time. The removal-rate data, still preliminary, follows, superimposed on earlier-reported in-duct removal rates achieved at this same facility with other sorbents.

B-PAC in-duct mercury removal of 70% was observed at an injection rate of only 1.5 lb/MMacf. Projecting slightly to 2.0 lb/MMacf, about 80% removal looks to result. This compares to approximately 50% removal at this rate with iodine-impregnated CB 200XF and 10% removal with plain PACs. So 80% removal with B-PAC and an ESP could cost on the order of $6,000/lb Hg, or about 10% that of alternate sorbents.[13]

Figure 14. In-flight mercury removal across the spray dryer at Stanton 10.

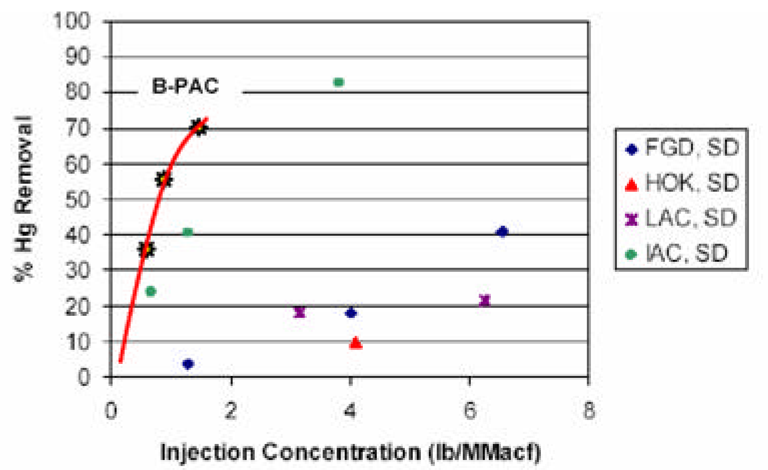


Figure 3. Mercury removal measured across the spray dryer at Stanton Station during parametric testing.

$$\left(\frac{2\,lb\,sorbent}{1{,}000{,}000\,acf}\right)\left(\frac{Nm3}{(80\%)8.5\,mg\,Hg}\right)\left(\frac{\$0.75}{lb\,sorbent}\right)\left(\frac{1.5\,acf\,@300F}{1\,scf}\right)\left(\frac{35.3\,scf}{Nm^3}\right)\left(\frac{10^9\,mgHg}{2.2\,lb\;Hg\;removed}\right) = \$5{,}300\,/\,lbHg.$$

Future full-scale testing of B-PAC on the exhaust gas of Stanton Boiler No. 1, which indeed has just a cold-side ESP, is anticipated in early 2005.

B-PAC PRODUCTION PLANT

To meet the demand for sorbents engendered by such large, full-scale demonstrations – as well as permanent demand for such sorbents by power plants complying with new state emission limits, Sorbent Technologies has built the world's first dedicated utility mercury sorbent facility. This facility can produce enough B-PAC to supply a number of power plants on a permanent, ongoing basis. Moreover, with approximately six months notice, the facility can be easily expanded to supply additional power plants on a continuing basis.

Importantly, with B-PAC utilities can easily "try before they buy." Sorbent Technologies can inexpensively use its mobile sorbent injection trailer to perform full-scale trials for utilities ahead of any permanent installations. On the basis of such trials, Sorbent Technologies will offer commercial mercury-removal rate guarantees. With B-PAC™, high-performance, low-cost power plant mercury control is now commercially available.

CONCLUSIONS

The evidence is building from an increasing number of diverse power plant trials that simple B-PAC injection ahead of an existing particulate collector can be a comparatively inexpensive, yet uniformly effective mercury emission reduction strategy. With the completion of Sorbent Technologies' B-PAC production plant, any U.S. power plant can now cost-effectively reduce its mercury emissions on an ongoing basis if it chooses to.

ACKNOWLEDGEMENTS

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