ADDITIONAL B-PAC™, H- PAC™ and C- PAC™ TRIAL RESULTS

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ABSTRACT

Earlier papers have reported on successful full-scale trials of Sorbent Technologies' family of brominated powdered activated carbons: B-PAC™ for lower temperature applications such as cold-side electrostatic precipitators (ESPs) and baghouses, C-PAC™ for applications which require a concrete friendly sorbent to allow continued sale of the fly ash, and H-PAC™ for high temperature applications. This paper covers two more full-scale demonstrations.

The first test covered in this paper is the work performed at the Progress Energy H.F. Lee Unit 2. This boiler has a capacity of about 83 MW and it fires low-sulfur bituminous coal. Unit 2 is equipped with a hot-side ESP for particulate control. This test was composed of baseline measurements and parametric injection tests only and was privately funded. The fly ash from this boiler is not sold and, therefore, H-PAC™ was the primary mercury sorbent used in the testing. In addition, an experimental, lower-cost version of H-PAC™ was tested along with the bromine salt impregnated Norit Darco Hg LH sorbent.

The testing at Lee Unit 2 extended the temperature at which H-PAC™ had been previously tested with the sorbent injection temperatures reaching as high as 850^{O}F at full boiler load. The H-PAC™ sorbent was able to achieve a mercury reduction of 60% at an injection rate of 10 lb/MMacf at high load and temperature, while a mercury removal rate of 75% was achieved at low load and temperature at the same injection rate.

The second test covered in this paper is the United States Department of Energy co-funded trials at Midwest Generation's Will County Unit 3. This boiler fires subbituminous coal and is equipped with a hot-side ESP. The fly ash from this boiler is sold and, therefore, the high temperature version of C-PAC™ was the primary sorbent used. H-PAC™ sorbents and the Norit Darco Hg-LH sorbent were also tested in the parametric tests. It should be noted that the long-term test of 30 days was eliminated in the Will County test program and replaced by a six day continuous run due a reduction in funding.

The C-PAC™ was injected at rates of 3 and 5 lb/MMacf in the first round of parametric tests and injected at the latter rate during the continuous run. Mercury removal rates between 60% and 73% were observed at an injection rate of 5 lb/MMacf.

INTRODUCTION

The mercury-removal performance of plain powdered activated carbons (PACs) and impregnated PACs have proved to be 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 family of brominated mercury sorbents (B-PAC™, C-PAC™ and H-PAC™) have consistently demonstrated high mercury removal rates at relatively low injection levels across a wide variety of coals and configurations.[1-3]

In this paper, the injection performance of C-PAC™ and H-PAC™ observed in recent full-scale tests performed by Sorbent Technologies Corporation are discussed. Note that the mercury emission reduction data presented here count only sorbent-injection-related reductions and not any additional reductions due to native mercury removal already achieved at the sites.

FULL-SCALE RESULTS

Bituminous Coal & Hot-Side ESP: Progress Energy's H.F. Lee Unit 2

The Progress Energy H.F. Lee Plant is located in Goldsboro, North Carolina. The plant is shown in Photograph below.

Photograph 1. Progress Energy H.F. Lee Plant.

H.F. Lee Unit 2 is the second unit from the right. This boiler was built in 1952 and has a gross capacity of about 83 MW. The boiler is not base-loaded but has an operating factor of about 56%.

The boiler is tangentially fired and uses low sulfur (0.8% as received) bituminous coal from the Eastern United States. The coal is typical of bituminous coal and contains, on an as received basis, approximately 10% ash, 7% moisture, 1500 ppm of chlorine, 12,500 Btu/lb. The coal mercury is somewhat lower than the typical bituminous coal at about 0.07 ppm, on a dry basis. The unit is not equipped for SO_2 or NO_X control.

A hot-side ESP with an SCA of 309 is used for particulate control. The inlet temperature to the ESP is more than 775^{O}F and the flue gas flow rate is about 600,000 acfm when at full load. The fly ash contains more than the maximum LOI limit of 5% for use in concrete. Fly ash is sluiced to an ash pond.

These tests were privately funded and consisted only of parametric injection tests. PS Analytical mercury monitors were used to measure flue gas mercury on the cold-side of the ESP. Coal and fly ash samples were taken during the testing but there was no attempt to calculate mercury mass balances since parametric fly ash samples are not representative of the fly ash which will be produced in a long-term test. The reason for this is that parametric fly ash samples are always diluted with an unknown amount of untreated ash.

The results from of the parametric testing at Lee 2 are shown in the Table 1.

Table 1. Lee 2 Parametric Test Results

Date	Sorbent	Load, MW	Injection Rate lb/MMacf	Injection Temp., F	Mercury Removal, %
2/16/07	H-PAC	83	5	789	41%
2/16/07	H-PAC	83	10	795	60%
2/17/07	H-PAC	44	5	569	56%
2/18/07	H-PAC	44	10	547	75%
2/18/07	H-PAC	44	15	563	84%
2/18/07	H-PAC-C	44	10	578	74%
2/19/07	H-PAC-C	83	5	809	25%
2/19/07	H-PAC-C	83	10	827	34%
2/20/07	Norit LH	82	10	774	42%
2/20/07	Norit LH	82	10	793	38%[#]

[#] Distributing Lances

On Friday February 16th, H-PAC™ sorbent was injected at two rates, 5 and 10 lb/MMacf. The temperature at the point of injection was about 790^{O}F during these two runs. The mercury removal rates for these two injection rates were 41% and 60%, respectively. This is good mercury removal at temperatures higher than previously tested.

At low load and temperature, the H-PAC™ sorbent gave higher Hg removal rates of 56%, 75% and 84% at injection rates of 5, 10 and 15 lb/MMacf. The data for the latter two runs is presented in Figure 1.

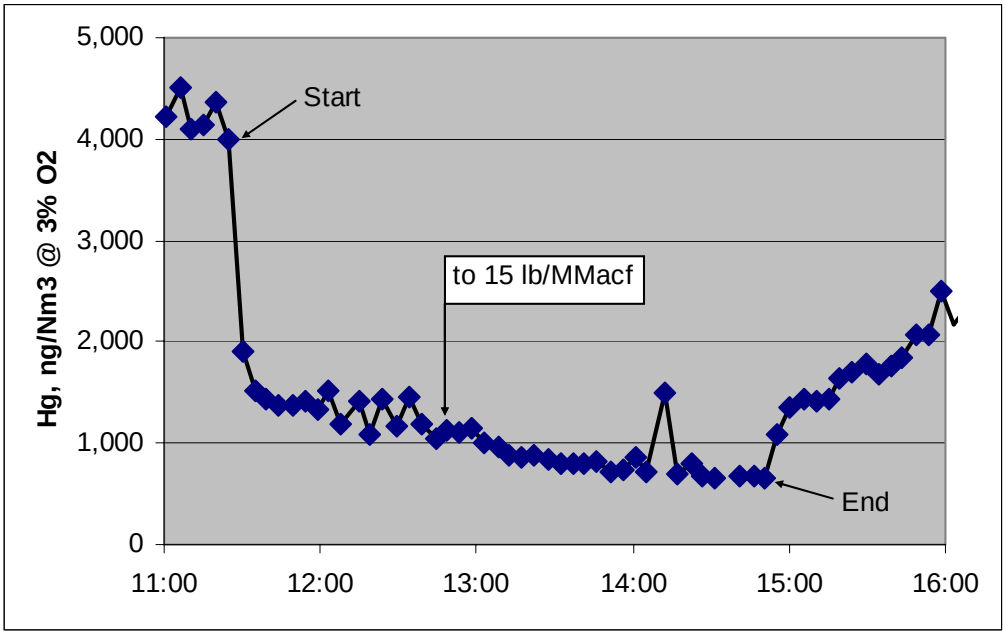

Figure 1. Lee 2 at Low Load H-PAC™ at 10 and 15 lb/MMacf on 2/18/07

The low load and temperature runs resemble closely those obtained in an injection run in a cold-side ESP. The mercury level drops rapidly after the injection begins but slowly declines over time as the sorbent builds up in the system and adds to the mercury removal. At the end of the injection run, the mercury level does not jump either to or above the baseline level but slowly climbs back to the baseline level as the sorbent in the system continues to capture mercury. In the high temperature runs, the mercury level drops rapidly to a specific mercury level and stays there until the end of the run when it rapidly returns to baseline levels.

A lower-cost, experimental version of H-PAC™ (H-PAC-C) was tested and did well at low temperatures but not at high temperatures. However, the full load temperatures under which this sorbent was evaluated were 20^{O}F to 40^{O}F higher than during the other two high load test days (2/16 and 2/20). It is unknown whether the added temperature had any negative impact on the H-PAC-C performance.

The Norit Hg LH sorbent was tested on 2/20/07 and it did not perform as well as did the H-PAC™ sorbent. At high load and an injection rate of 10 lb/MMacf, the H-PAC™ sorbent provided 60% mercury removal, while the Norit Hg LH gave only 42% mercury removal. The use of distributing lances with three holes per lance did not improve the performance of the Norit Hg LH sorbent when compared to being injected with open lances.

The data from the parametric testing at Lee 1 is summarized in Figure 2.

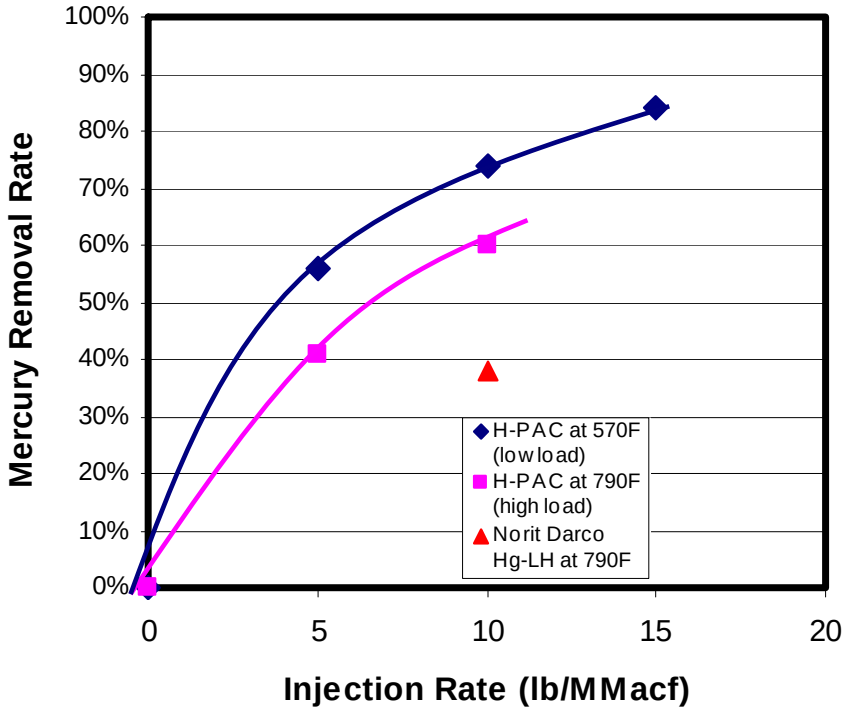

Figure 2. Summary of Parametric Testing Results at Lee 2

No deleterious effects on the balance of plant or ESP performance observed in these tests although they were of short duration.

Subbituminous Coal & Hot-Side ESP: Midwest Generation's Will County Unit 3

As part of the United States DOE National Energy Technology Laboratory's "Large Scale Mercury Control Technology Field Testing Program – Phase II", Sorbent Technologies evaluated C-PAC™ and H-PAC™ at Midwest Generation's Will County Unit 3 in July and August of 2007.[4] Midwest Generation's Will County Plant is the third and final host site in this DOE project. The plant is shown in Photograph 2.

Photograph 2. Midwest Generation Will County Plant

There are two boilers combined to compose Will County Unit 3. They were commissioned in 1955, are identical, and are fired at the same rate. One of the two boilers is called the "Reheat" boiler since it reheats the steam while the other is called the "Superheat" boiler since it superheats the steam for use in electrical generating turbines. Each boiler has its own ductwork and hot-side ESPs for particulate control. The Will County Unit 3 boilers are tangentially fired with a capacity of 278 MW. The testing was performed on the "Superheat" boiler or essentially half of the unit capacity (139 MW). The boiler is not base-loaded but has an operating factor of about 50%.

The boilers fire PRB coal with as received moisture, ash and sulfur contents of about 28%, 4% and 0.3%, respectively. The as received heat content of the coal is about 8700 Btu/lb. The mercury content of the coal is expected to be 0.10 ppm, somewhat higher than for the typical PRB coal. The boilers are equipped with low NO_X burners.

The boilers have hot-side ESPs each with an SCA of 233. The inlet temperature to the ESPs varies between 500^{O}F and 700^{O}F, depending upon load. The flue gas flow rate to each ESP is approximately 500,000 acfm at full load. A dry ash removal system is used since some of the fly ash is sold. Both C-PAC™ and H-PAC™ sorbents were used in this test program. The parametric tests and continuous run with C-PAC™ were performed first to avoid any impact on the fly ash properties by non-concrete friendly sorbents. There was a second round of parametric tests after the continuous run in which other H-PAC™ sorbents and Norit Hg LH were evaluated.

CFD Modeling for Will County Unit 3

Fuel Tech performed the CFD modeling of Will County Unit 3. The ductwork from the boiler exit through the ESP inlet was modeled. There is no air preheater in this duct run since this is a hot-side ESP. There are numerous turning and straightening vanes in the ductwork which made both the modeling effort and the selection of an injection location difficult. In addition, the flue gas makes an abrupt right turn into the ESP plenum. The ductwork modeled is shown in Figure 3.

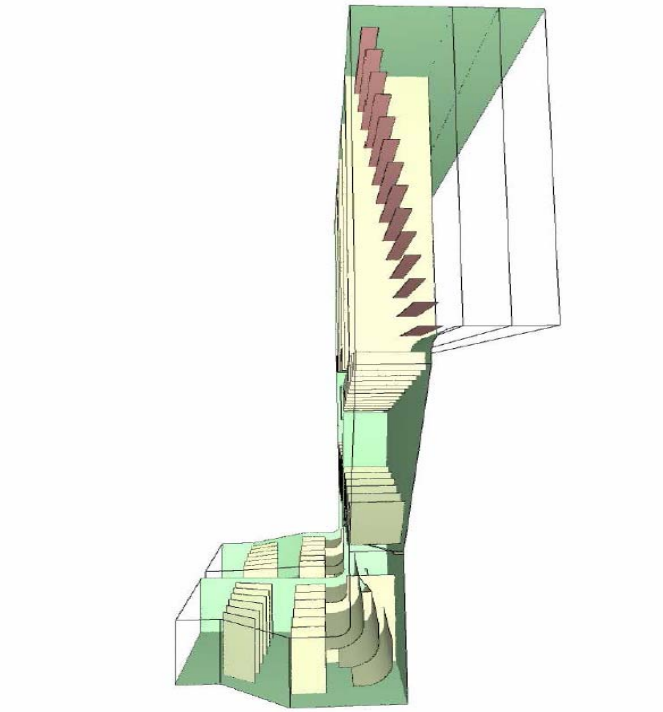

Figure 3. Ductwork at Will County Unit 3 Modeled

The flow is from the bottom left to the top right. There are a series of existing ports right before the straightening vanes in the vertical ductwork. The ductwork is actually two ducts at this point, each about 4.5 feet deep by 20 feet wide. The first location evaluated was the existing ports. No injection lance arrangement could be found to provide a good sorbent distribution when injecting into the existing ports. It was concluded that the injection location would have to be moved back towards the boiler and in the horizontal ducts in order to obtain good distribution. The area selected was just in front of the vanes in the horizontal section of the ductwork shown in Figure 3. The sorbent distribution when injecting at the new location is shown in Figure 4.

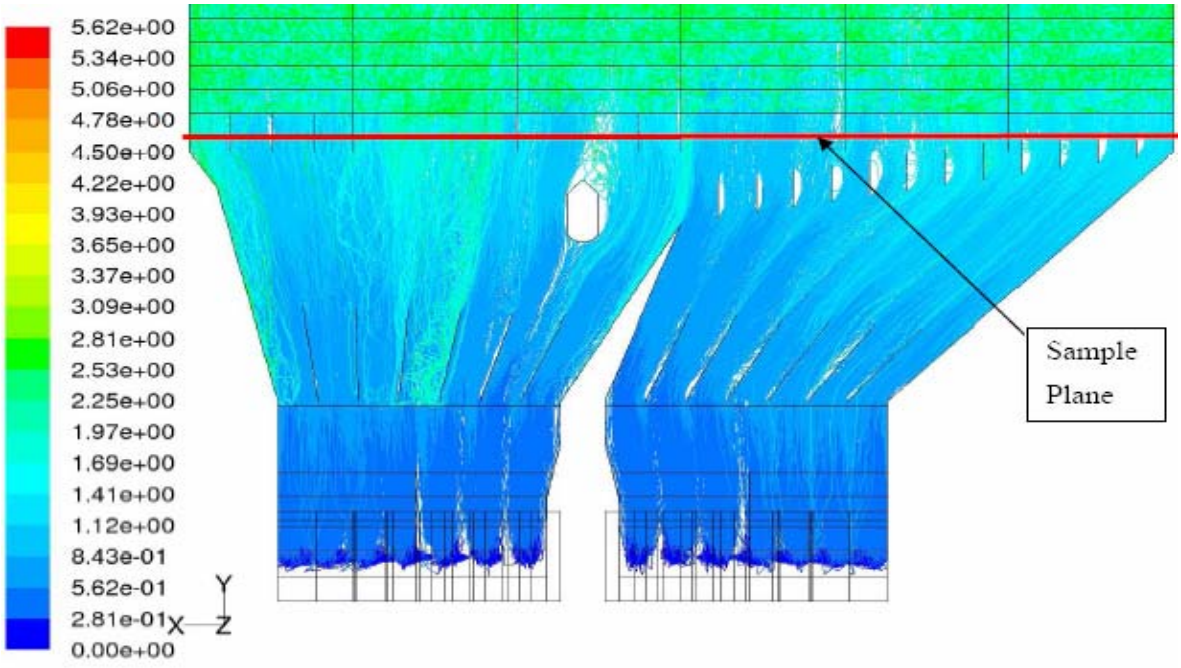

Figure 4. Injection into the 14 New Ports at Will County 3

The sorbent distribution using this injection location is much better at the ESP entrance but still not ideal. Added residence time and more duct obstructions is the reason for the better sorbent distribution. Therefore, this injection arrangement was selected for use at Will County.

Sorbent Technologies has developed in our laboratories in Twinsburg Ohio lances designed to provide maximum sorbent distribution in the shortest residence time possible. These lances, named X-a-Lance, were designed for applications such as hot-side ESPs where the residence time between the point of injection and the particulate control device is usually very short. These lances could also have use in other applications where there is a minimal residence time before the particulate control device or there is more laminar flue gas flow. The CFD modeling confirmed that the new lance design had the potential to provide better sorbent distribution in this application. The new lance designed was evaluated in the test program at Will County Unit 3.

Baseline Measurements, First Parametric Tests and Continuous Run

At the time of this writing, the program is still ongoing and only some of the preliminary results from the baseline measurements, first parametric tests and the continuous run are available. Sorbent Technologies personnel arrived at the Midwest Generation Will County Station on July 30, 2007 in order to begin assembling the equipment for this trial. PS Analytical mercury monitors were used to make mercury measurements before and after the hot-side ESP at Will County Unit 3. The inlet monitoring position was upstream of the sorbent injection location. Appendix K sorbent trap samples were also taken at the outlet location throughout the test program. In addition coal and fly ash samples were taken. The fly ash sampling was extensive since these samples were to be evaluated for their cementitous properties as well as the mercury content. The fly ash mercury content was measured by Sorbent Technologies using an Ohio Lumex instrument while both LaFarge and Headwaters Resources evaluated the concrete properties of the fly ash.

The baseline measurement period began on August 5 and ran until the first parametric testing with the C-PAC™ concrete friendly sorbent began on August 8. The data from the PS Analytical mercury monitors and the Appendix K test for the baseline period is shown in Figure 5.

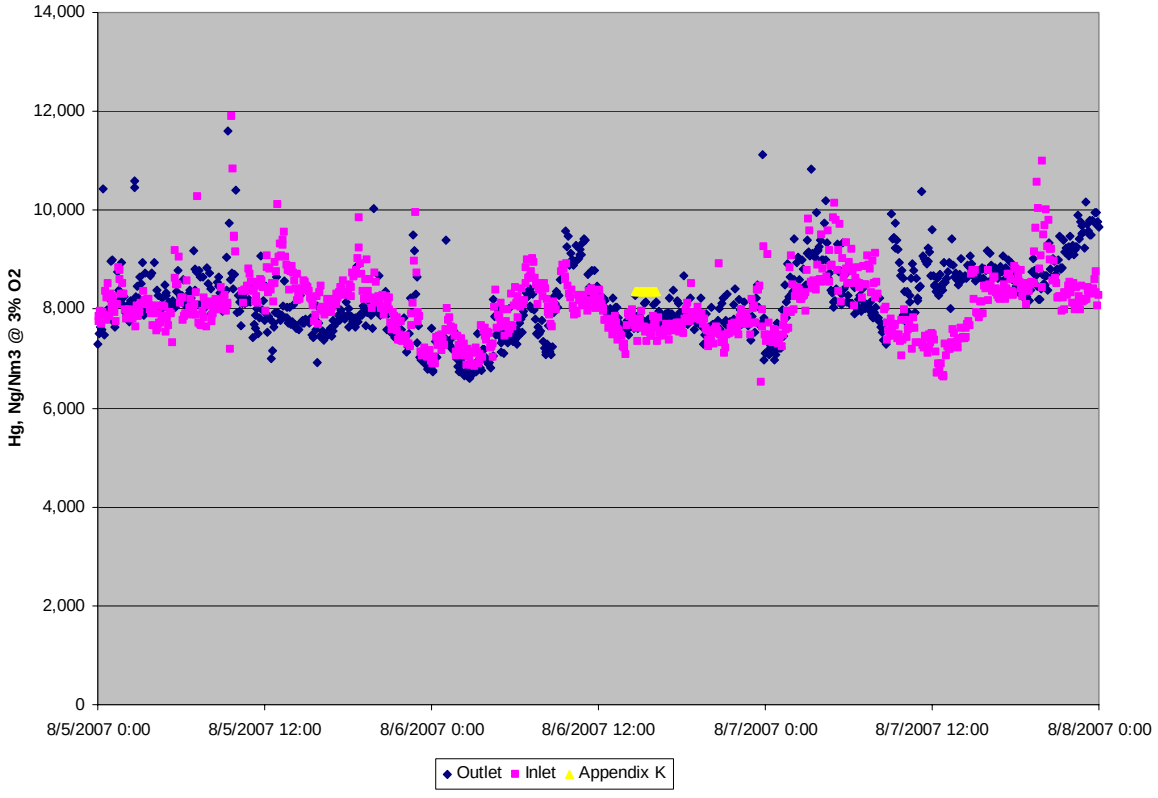

Figure 5. Mercury Monitor and Sorbent Trap Data for the Baseline Period at Will County Unit 3. Over the baseline period, the mercury concentration measured at the inlet and outlet locations was nearly the same. This was expected since the ESP operates at temperature between 500^{O}F and 700^{O}F, well above the temperature at which fly ash carbon can capture flue gas mercury. In addition, there is not much carbon in this fly ash since a subbituminous coal is fired.

The flue gas mercury concentration as measured by the PS Analytical monitors averaged about 8000 ng/Nm^3 corrected to 3% oxygen. This mercury concentration was expected based upon the coal mercury content. The Appendix K sample indicated that the mercury concentration was slightly higher (about 7%) than indicated by the PS Analytical monitors for the same monitoring period.

The C-PAC™ concrete friendly sorbent parametric tests began on August 8. C-PAC™ was injected at rates of 3 and 5 lb/MMacf using an array of 28 open ended lances on that date. The PS Analytical monitor indicated that the mercury reductions at these injection rates were about 38% and 55%, respectively. After the completion of the parametric testing on August 8, the injection lances were changed from the open ended design to the X-a-Lance distributing lance design. The same sorbent was used at the same injection rate on August 9 with the new lances. The data from the PS Analytical mercury monitors and the Appendix K sorbent trap for the second day of parametric testing is shown in Figure 6.

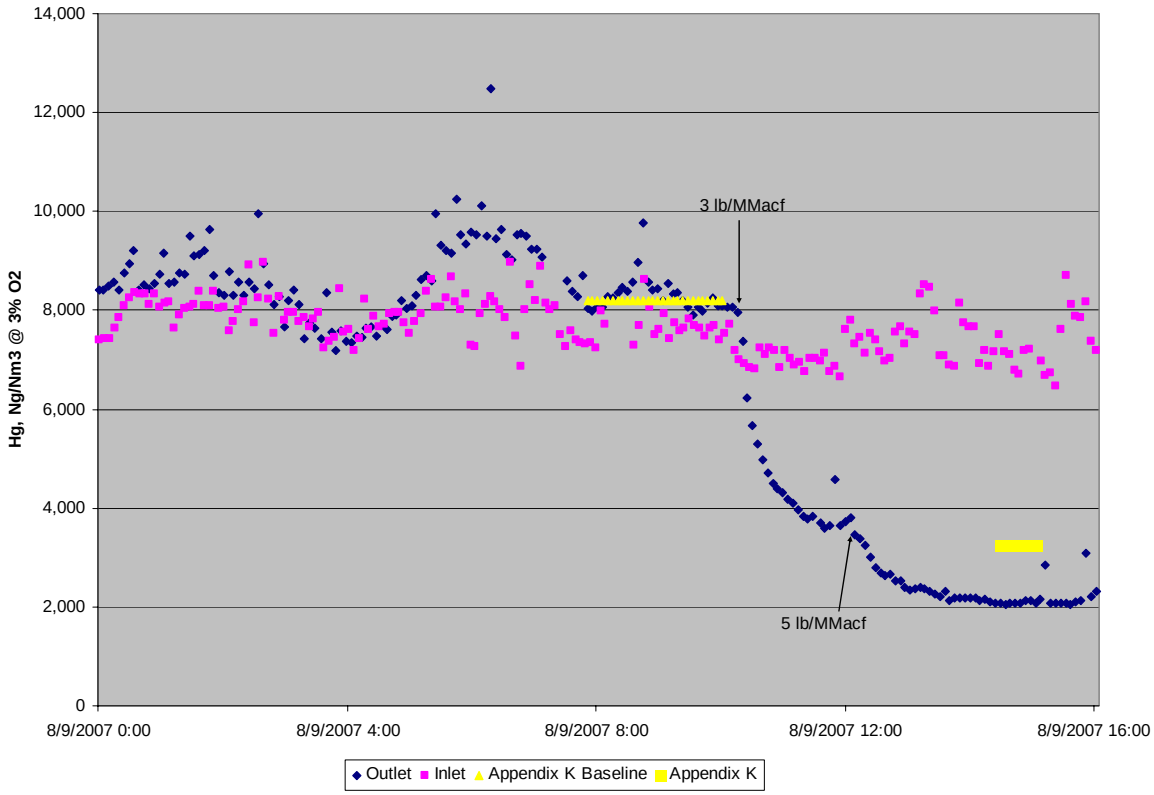

Figure 6. Parametric Injection Test of C-PAC™ using the X-a-Lances at Will County Unit 3.

The PS Analytical data indicated that the mercury removal was 55% at an injection rate of 3 lb/MMacf and 73% at an injection rate of 5 lb/MMacf. This is a dramatic improvement in mercury removal which must be credited to the use of the newly developed X-a-Lance which aids in sorbent distribution. The X-a-Lances were used throughout the remainder of the program.

Appendix K sorbent traps were taken at the ESP outlet before the injection run and when injecting at the 5 lb/MMacf injection rate. The result from the period before injection corresponds very well to the PS Analytical data for the same time period. However, the Appendix K test taken during the injection at 5 lb/MMacf indicates

that the mercury removal was only 61%, instead of the 73% indicated by the PS Analytical data. The reason for this difference is unknown at this time but more light will be shed on the subject when the fly ash samples are analyzed.

The continuous run at Will County continued immediately after the parametric test on August 9. The second set of parametric tests with non-concrete friendly mercury sorbents was scheduled for directly after the continuous run but had to be delayed due to two outages at Unit 3. Thus, none of these results are available at this time.

Sorbent Production

The sorbents used in this test program, as well as those for commercial customers, were produced in the Sorbent Technologies' mercury sorbent facility in Twinsburg, Ohio. This facility has been upgraded in order to be able to produce up to 4,000 pounds per hour of any of our family of brominated mercury sorbents: B-PAC™, C-PAC™, or H-PAC™. Sorbent Technologies is currently exploring options to further in crease the capacity of this facility to supply a number of power plants on a permanent, ongoing basis.

Sorbent Technologies is exploring the potential for building a 40,000,000 million pound per year facility somewhere in the Midwest in order to better meet the needs of the customers located there.

CONCLUSIONS

The evidence is building from an increasing number of diverse power plant trials that H-PAC™ injection ahead of an existing hot-side ESP can be a comparatively inexpensive, yet an effective mercury emission reduction strategy. The testing at the Progress Energy Lee Unit 2 demonstrated that H-PAC™ can used at temperature higher than previously expected. The testing at the Midwest Generation Will County Unit 3 demonstrates that there is potential for the high temperature version of C-PAC™ to provide effective mercury removal and minimal impact on the fly ash properties. Sorbent Technologies' sorbent production plant has expanded production in order to supply existing commercial customers. In addition, Sorbent Technologies is evaluating a further expansion of this facility in Twinsburg, Ohio plus the construction of an even larger facility somewhere in the Midwest.

ACKNOWLEDGEMENTS

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