



DEVELOPMENT OF MERCURY CONTROL TECHNOLOGIES

Stanley J. Miller
Principal Investigator

Key Personnel: Stanley J. Miller (EERC), Grant E. Dunham (EERC), Michael J. Holmes (EERC), Edwin S. Olson (EERC), Blaise A. Mibeck (EERC), Michael D. Mann (EERC), and John H. Pavlish (EERC)

Project Description

This project is intended to develop and test promising mercury control technologies such as sorbents that will provide rapid in-duct capture of mercury, catalysts that will oxidize elemental mercury (Hg^0) so it can be captured in a wet scrubber, modification of wet scrubbing techniques to enhance mercury capture or cleaning of the coal before combustion. A further goal is to determine the effects of flue gas constituents on mercury capture by sorbents. This information has been used to develop and refine a model to explain the mechanisms for mercury capture, oxidation, and rerelease by sorbents in a flue gas. A full-factorial matrix of bench-scale fixed-bed tests was completed to determine the effects of the various flue gas constituents on the capture of mercuric chloride (HgCl_2) by an activated carbon (AC). Under some conditions significant reduction of the oxidized mercury (Hg^{2+}) to Hg^0 occurs across the AC bed. Ongoing protocol development for evaluating potential mercury sorbents included bench-scale tests with an entrained-flow reactor (EFR).

Goal

The overall goal is to develop cost-effective mercury control in an approach consistent with the research need itemized in the U.S. Environmental Protection Agency's (EPA's) *Mercury Study Report to Congress*.

Specific goals are to:

- Further develop protocols to test the required sorbent reactivity and capacity necessary for effective mercury capture.
- Test new sorbents (based on previous successes at the Energy & Environmental Research Center [EERC] and elsewhere) that are likely candidates for rapid in-duct sorption of mercury and can overcome the SO_2 - NO_2 -induced breakthrough problem.
- Further refine the understanding of flue gas concentrations on sorbent reactivity, capacity, and desorption.
- Evaluate an advanced technology concept for increased sorbent utilization and mercury control downstream of a particulate collection device.
- Investigate the effect of carbon basicity on the AC sorption mechanism.

- Determine the effects of flue gas constituents on the capture of HgCl_2 by an AC in a fixed-bed reactor.
- Evaluate additives that can be utilized with flue gas desulfurization (FGD) systems to consistently achieve 90% Hg capture.

Rationale

Mercury emissions from combustion systems are recognized as a significant source of anthropogenic mercury. EPA has recently proposed both a maximum achievable control technology control strategy and a cap-and-trade approach. Depending on the outcome of this decision, several approaches may be taken to control mercury emissions from coal-fired boilers, including sorbent injection, enhancing the ability of wet scrubbers to capture mercury, or cleaning the coal. While many coal-fired boilers are not equipped with wet scrubbers, almost all are equipped with either an electrostatic precipitator (ESP) or a baghouse. Sorbent injection upstream of either an ESP or a baghouse appears attractive because it has the potential to control both Hg^0 and Hg^{2+} species, would appear to be easy to retrofit, and would be applicable to both industrial and utility boilers.

Since mercury in the gas stream from coal combustion is present in only trace quantities, usually in the range of 5 to 10 $\mu\text{g}/\text{m}^3$ (about 1 ppbv), theoretically only very small amounts (0.1% to 0.2% of a typical dust loading) of sorbent may be necessary. At these levels, the amount of sorbent material in the ash would not be expected to have an impact on control device performance or ash disposal but may have an impact on utilization. One example where ash utilization was negatively impacted by the use of small amounts of AC was seen during testing at the Pleasant Prairie Power Plant where the resulting ash failed foaming index tests preventing use in concrete manufacture [1]. Stability of the mercury captured in ashes with carbon-based sorbents has been demonstrated in recent tests where leachabilities and volatilities have generally been shown to be negligible [2, 3]. Even though the percentage of carbon in the fly ash is small, the amount of carbon required to serve the U.S. and Canadian market is expected to be enormous, but by regenerating the sorbent, these amounts could be reduced significantly. Application of regeneration technology is targeted toward systems where sorbent and ash collection are separate or in combination with an ash and sorbent separation technique.

Previous bench-scale testing established that ACs, such as fine powdered Norit FGD AC, are effective for mercury capture in simulated flue gas mixtures containing components found in coal combustion gases. However, a significant NO_2 - SO_2 -water interaction was identified that limits the capacity and results in release of Hg^{2+} species [4]. An HCl effect was also identified during these tests. Tests have been completed to determine the effects of SO_2 and NO_2 concentration. Further information on the effects of HCl concentration will help to expand the current model for mercury interaction with AC in a flue gas. The current model (discussed later in more detail) is based only on reactions of Hg^0 , flue gas, and carbon and does not involve any reactions with HgCl_2 . Expansion of the model to include effects with HgCl_2 is planned in the future.

FGD systems have shown promise for capture of 80% to 95% of the Hg^{2+} but virtually no removal of Hg^0 . Various researchers have been testing reagents or additives to enhance the removal of the Hg^0 . Results at McDermott demonstrated that ethylenediaminetetraacetic acid (EDTA) and H_2S can enhance mercury removal in the scrubber [5]. Argonne National Laboratory showed that NOXSORB is also effective in enhancing mercury removal in a scrubber. Radian employed a variety of agents upstream of the scrubber to preoxidize the mercury to enhance scrubber performance [6]. If the cap-and-trade approach is accepted by EPA, existing pollution control devices such as scrubbers and coal-cleaning methods will be used to meet initial mercury emission limits.

Approach

Fixed-bed tests were performed to determine the capacity of promising sorbents and to evaluate the effects of HCl concentration on Hg⁰ capture. Fixed-bed tests were also performed to evaluate the effects of flue gas constituents on the capture of HgCl₂ by AC.

Previous work has shown that very high sorbent reactivity and capacity can be achieved under some conditions (e.g., HCl present without SO₂ and nitrogen oxide [NO_x]). However, it is now evident that if all of the normal flue gas components are present, the carbon sorbent is poisoned, and the capacity for mercury capture is limited. However, even though the capacity may be limited, the initial reactivity of the sorbent is still important. A small-scale carbon feeder was designed, built, and tested for use with the EFR. The single-wire ESP and gas delivery system for the EFR were also evaluated. Initial bench-scale tests were then conducted to develop testing protocol and begin verification of the system.

On the basis of the results of the previous sorbent testing matrix where the interactions of the various flue gas components were determined [7] and an x-ray photoelectron spectroscopy (XPS) investigation in another project that further elucidated the competitive interaction of the acidic gases, the dual functionality model for mercury–flue gas interactions with carbon sorbents was modified.

A process to regenerate carbon sorbents that would reduce the costs associated with using sorbents for mercury control was evaluated. This technology regenerates sorbents by removing components derived from coal-fired flue gas that are consuming active sites that could otherwise be used for mercury capture. Several bench- and pilot-scale tests were performed to optimize the regeneration process conditions. Initial tests were also performed to determine the maximum number of cycles a sorbent can be regenerated and still remain effective.

Earlier tests that evaluated the effects of all of the flue gas constituents on the capture of Hg⁰ by an AC revealed a highly significant poisoning effect when SO₂, NO₂, and moisture are present. A similar full-factorial matrix has now been completed with HgCl₂.

The initial work to evaluate additives that can be utilized with FGD systems was performed on the EERC wet scrubber system. This two-story limestone scrubber is attached to the exit piping of the conversion and environmental process simulator (CEPS). The initial work indicated that HgCl₂ was easily adsorbed on the surface of the scrubber system which is made of Plexiglas, which led to poor mass balances. Based upon the problems with direct use of the scrubber, focus shifted to chlorination of the mercury directly upstream of the scrubber. During the first activity, Hg⁰ was vaporized in the CEPS. A simulated flue gas consisting of SO₂, NO, O₂, and N₂ was injected into the refractory-lined duct. Inlet and outlet Hg concentrations were determined using an online mercury analyzer. A comparison between molecular chlorine (Cl₂) and HCl was carried out focusing on the possible heterogeneous reactions (the refractory-lined duct may host active sites). The principal impacts from SO₂, O₂, and NO were investigated. A second activity designed to further investigate the impacts of principle flue gas components, including Cl₂, SO₂, NO, H₂O, CO₂, and O₂, on mercury oxidation utilized a quartz bench-scale reactor. A statistical experimental design was implemented to isolate singular and/or combined effects of the flue gas.

Progress

Bench-Scale Testing (fixed-bed and entrained-flow reactor)

A significant difference was observed in the performance of lignite-derived carbons tested at HCl concentrations of 50 ppm versus 1 or 0 ppm. The main differences were that the capture efficiency was initially poor and maximum capture rate was observed after about 20 minutes' exposure to the very low HCl gas concentrations, whereas the maximum rate achieved with the high HCl conditions occurred essentially at the start. This effect was attributed to either a catalytic effect of the HCl on the oxidation rate or to a promotional effect on the generation of active oxidation sites. HCl is not itself an oxidizing agent since it is already in a highly reduced form. Since the effect is exhibited as a gradual improvement of capture efficiency, the promotional effect appeared to be the better hypothesis. That this is an effect on the oxidation site is deduced from the concept that HCl would poison a basic binding site for Hg(II) and would not, therefore, be likely to increase the sorption capacity at any time. This characteristic has been labeled the induction peak or induction period and provides another indication of the performance of the sorbent. Bench-scale tests were also performed to evaluate the following.

Outside Sorbents: Tests were performed to evaluate two sorbent materials provided by an outside company that had shown good mercury capture in other applications. The fixed-bed tests showed almost immediate breakthrough with very little mercury capture.

Surface Area/Carbon Type: A variety of carbon types were selected to determine whether surface area or some other intrinsic structural factor is a primary determinant of mercury capture on carbons. The carbons included aerogel carbon, chemically activated carbon, fullerene soot, and AC from furfuryl alcohol carbonization. One of the aerogel samples, which was obtained by grinding a carbonized sheet of aerogel and sieving to -400 mesh, did not reach a final breakthrough point (0% capture) until 7 hours into the test. This is not typical behavior for an AC. There may be two effects to consider. One simple explanation for the increased capacity is that the larger surface area may result in more binding sites. Another explanation is that promotion of the catalytic site for oxidation is slower in this carbon, resulting in longer time for maximum mercury capture and a longer time to build up the sulfuric acid concentration which poisons the sites. A chemically activated carbon produced from a North Dakota lignite showed very good initial capture (95+%) with no induction period, and breakthrough at about 1.5 hr. This appears to be an improvement over the FGD carbon, but would likely be more costly to produce. Test results for the fullerene soot showed a poor initial capture of 30%, increasing to only 40% and then very gradual breakthrough. Clearly this and other soots lack the definite graphene edge structures present in ACs from coals and aerogel carbons. The AC prepared by steam activation of a precursor carbon obtained by polymerization and carbonization of furfuryl alcohol in acid captured no mercury at all.

Acid Promotion Effects: The significant difference observed in the performance of lignite-derived carbons tested at HCl concentrations of 50 ppm versus 1 or 0 ppm was attributed to either a catalytic effect of the HCl on the oxidation rate or to a promotional effect on the generation of active oxidation sites. This hypothesis led to another more practical hypothesis: that the activity could be promoted by pretreating the carbon sorbent with HCl. A gaseous pretreatment method failed to provide effective promotion of the active sites. Several carbons were prepared using an aqueous HCl pretreatment method. All showed a lack of an induction period. Sorbents that performed poorly before, such as the fullerene soot, also showed a decreased induction period, but still showed quick breakthrough. These tests showed that the aqueous HCl treatment will improve the reactivity of a good sorbent, but it will not make a good sorbent out of a poor one. Based on the success of the acid pretreatment, it was hypothesized that addition of an alkylating agent (instead of acid) to the basic sites on the carbon would generate a positively charged carbon or other atom on the carbon structure that could attract and oxidize the Hg⁰. A sample of the FGD carbon was pretreated with an ether

solution. The test results in low HCl conditions showed that the induction period was not eliminated as it had been with the acid pretreatment. The hypothesis that the mechanism of the HCl- and HBr-promoted reactions involves formation of Cl or Br atoms on the carbon surface which then react directly with Hg^0 was tested by impregnating a good radical scavenger on the carbon following the treatment with HCl. The test results showed that the induction period did not occur, but the sorbent did break through early. Since oxidation was not inhibited, the formation of chlorine atoms is not a likely mechanism.

Inorganics with Additives: A number of different inorganic sorbents were prepared and evaluated. They included calcium silicates, zeolites, and microporous clay composites. All showed essentially no mercury capture.

Carbon with Metal Additives/Lewis Acids: The carbons impregnated with Lewis acids (ZnCl_2 , SnCl_2 , and FeCl_3) all showed the absence of the induction period. These results gave confidence that the results can be explained by an acid promotion mechanism. Furthermore, the effect of adding bases to the sorbent may have simply resulted in reacting with the HCl in the gas and eliminating the promotion effect of the gaseous HCl at the oxidation site.

An HCl effect was identified during the previous full-factorial testing of the flue gas constituents, and tests have now been completed to determine the effects of varying the HCl, SO_2 , and NO_2 concentrations on Hg^0 capture. Tests were completed at HCl concentrations of 5, 50, and 100 ppm. The SO_2 concentration was varied between 300 and 1600 ppm, and the NO_2 concentration was varied between 5 and 20 ppm. This series of tests indicates the induction peak is related to the HCl concentration.

It has long been assumed that Hg^{2+} emissions would be relatively easy to control with AC injection. Since data were not available to confirm this and there were possible unknown interactions between the HgCl_2 , flue gas, and carbon sorbent, a full-factorial test matrix was completed to evaluate the effects of all the flue gas constituents on HgCl_2 capture by an AC in a fixed bed. Plots of the outlet mercury concentration as a function of time showed some similar interactions were the same as observed with Hg^0 injection. However, when SO_2 was present without NO_2 or HCl in the flue gas, the HgCl_2 was reduced to Hg^0 (see Figure 1).

The EFR has been used in previous work to study mercury transformations as a function of residence time and temperature in a real flue gas. In the past year, a small carbon feeder was designed, constructed, and evaluated for use with the EFR. Tests were also completed to shake down the flue gas delivery system and the single-wire ESP with the EFR. The purpose of the ESP was to capture nearly all of the sorbent so that a fixed bed of sorbent would not form on the backup filter. Results showed the ESP worked as expected, and no carbon penetrated to the backup filter. Another experimental issue was the amount of carbon captured on the walls of the EFR upstream of the ESP. When the ESP power was turned off, the backup filter was quickly coated with the carbon. The EFR was cleaned after each run, but there was little evidence of carbon on the walls of the EFR. The carbon feeder worked but will require some additional development to optimize the protocol. Dry N_2 is used as the carrier gas, and it dries the carbon over the time of a test. This makes it difficult to determine the actual carbon feed rate.

Shakedown tests with full flue gas and Hg^0 injection proved the EFR did not capture Hg^0 or affect its speciation. Tests were conducted with full flue gas, Hg^0 injection, and AC injection. Figure 2 is a typical plot generated using the EFR with the mercury bench-scale system. The mercury concentration at the outlet of the EFR is plotted as a function of time. A wall effect was observed during these tests. After carbon was injected for 1 hour, the carbon feed was turned off. However, the outlet concentration showed a breakthrough and the Hg^0 was oxidized. It appears this wall effect takes place in the ESP where the carbon is captured.

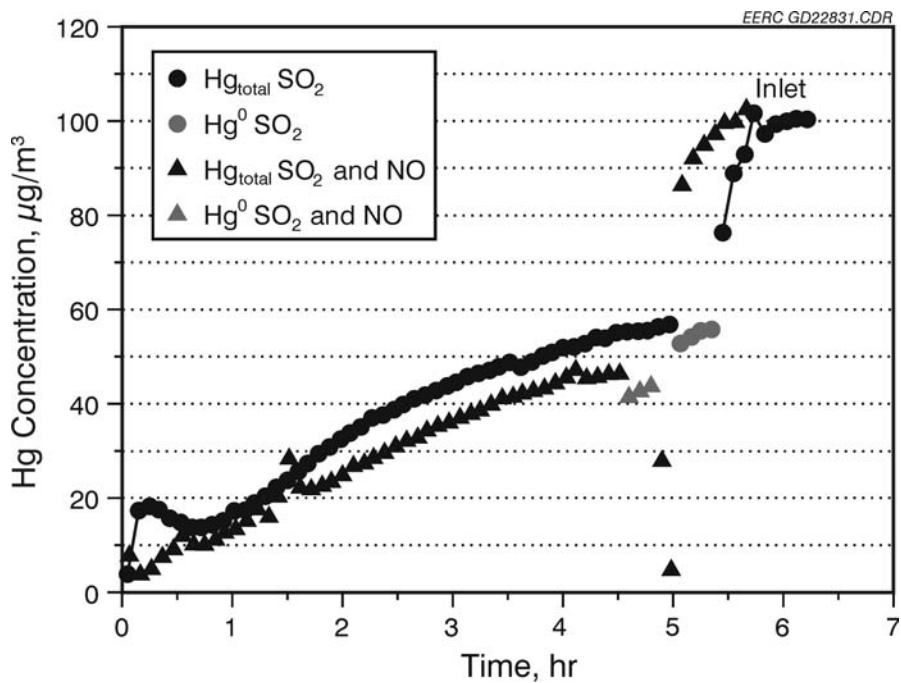


Figure 1. Reduction of $HgCl_2$ to Elemental Mercury Across a Fixed Bed of Activated Carbon

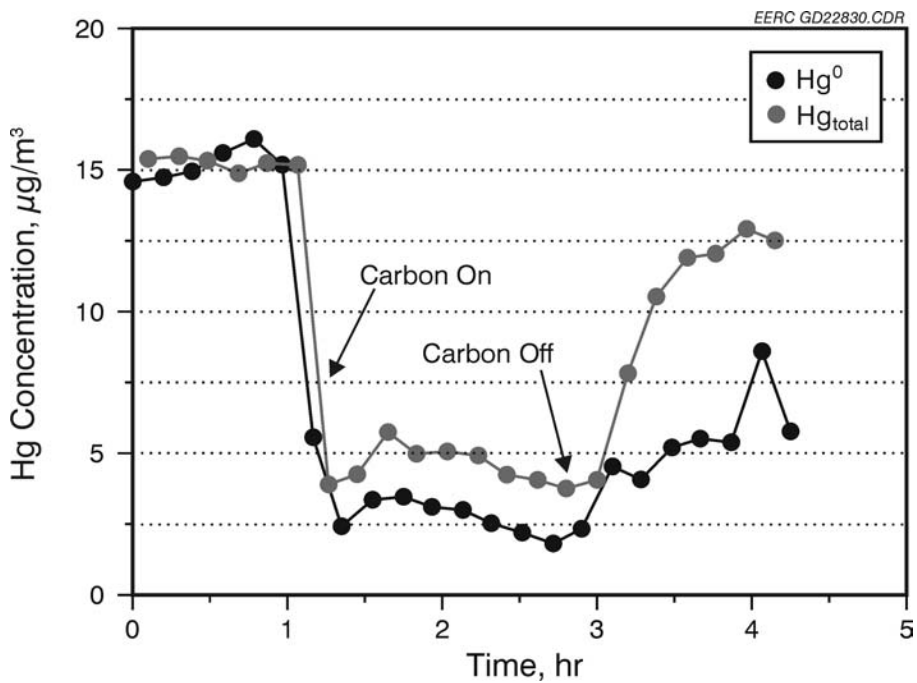


Figure 2. Mercury Capture as a Function of Time in the Entrained-Flow Reactor

Since the EFR is intended to look at reactivity, future tests will be of shorter duration to minimize this wall effect.

Model

Based on the results of the previous sorbent testing where the interactions of the various flue gas components were determined and an XPS investigation in another project that further elucidated the competitive interaction of the acidic gases, a dual functionality model for mercury–flue gas interactions with carbon sorbents was constructed (see Figure 3). This model shows the independent oxidation and capture chemistries that are consistent with the hypothesis that SO_2 poisons the binding site for Hg(II) capture on the sorbent surface, as well as the fact that mercury emitted from the sorbent after breakthrough is entirely an Hg^{2+} species. The current model for explaining the capture of Hg(II) formed in the initial oxidation step describes the sorption of the Hg(II) at a basic site on the carbon to form a nonvolatile salt [7, 8]. This occurs until the basic sites are exhausted by reaction with mainly the sulfur(VI) acids (sulfuric acid or bisulfate) that are produced by the oxidation of SO_2 . At the time of breakthrough, the Hg(II) , which continues to form, reacts with nitrate (from NO_2) or with HCl to form volatile salts such as the nitrate or chloride, and breakthrough occurs. In addition, the release of Hg^{2+} from the basic binding sites on the sorbent occurs, resulting from the conversion of these nonvolatile forms, in which the Hg(II) is initially captured, into volatile Hg(II) salts. Further elaboration of the mechanistic model was carried out on the basis of the results from the impregnated sorbents obtained in this project. The refined binding site model [9] offers more detail on the nature of the carbon site and its interaction with flue gases and Hg (see Figure 4). This model uses the concept of zigzag carbene structures recently proposed for electronic states at the edges of the carbon graphene layers [10] rather than oxygen functional groups suggested by other authors.

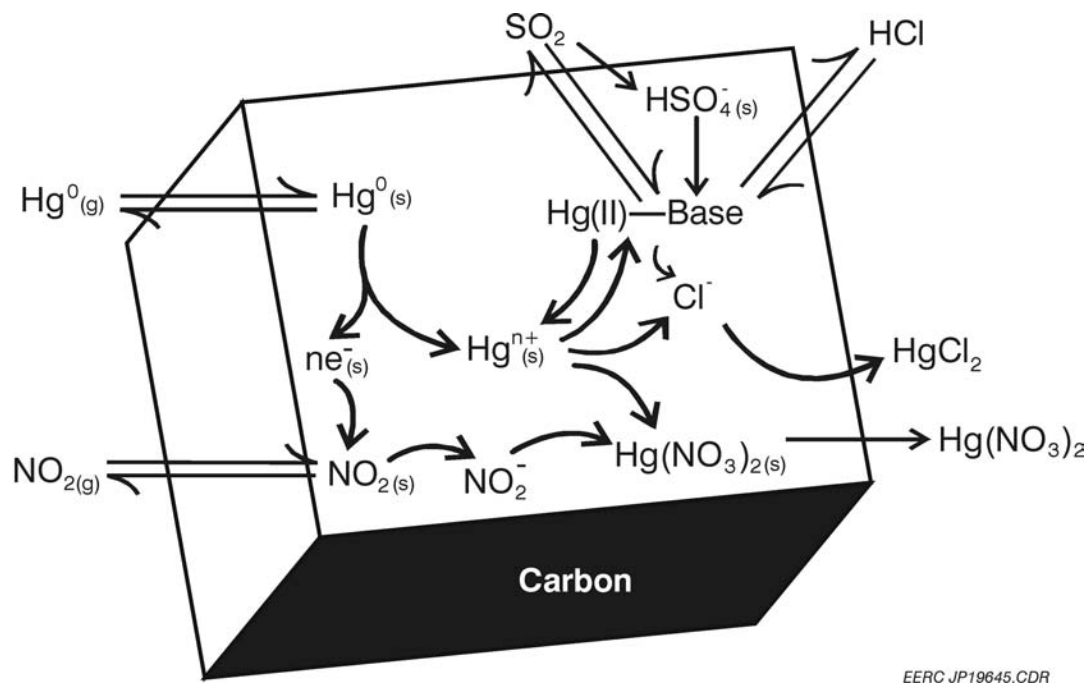


Figure 3. Mechanism for Mercury Capture on FGD Sorbent

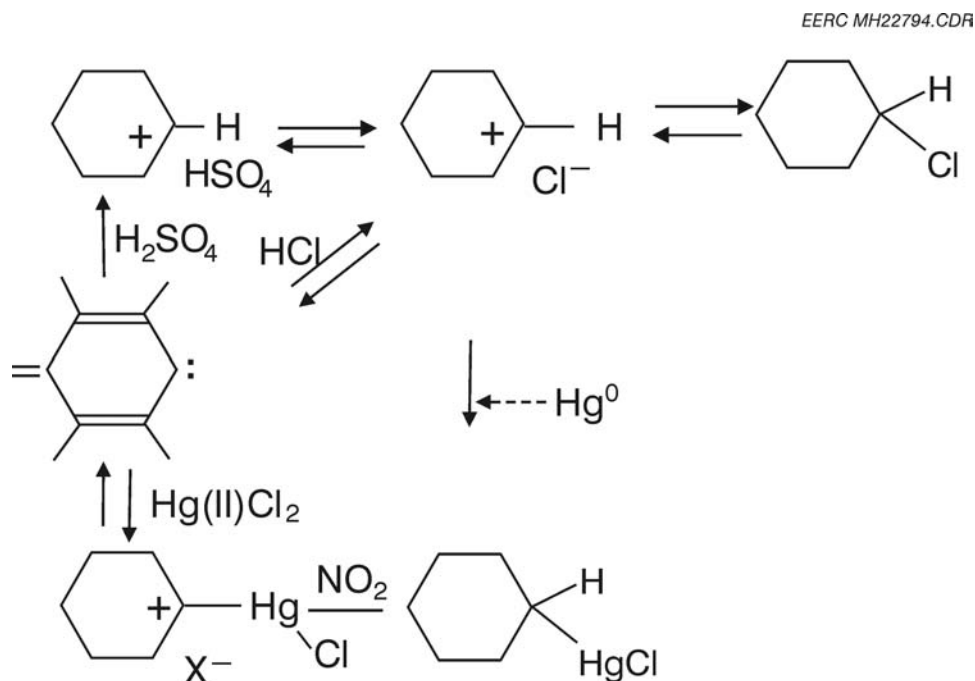


Figure 4. Oxidation Mechanism – Carbenium Ion Oxidant

Advanced Technology Concept

Figure 5 shows some typical sorbent breakthrough results for a lignite AC sorbent that has been regenerated. These results from bench-scale testing across a bed of carbon-treated fibers show that utilized sorbents can be effectively regenerated. Successive regeneration produces a sorbent that appears to be as effective as or more effective than the original sorbent. More tests are needed, however, to determine how many times a particular sorbent can be regenerated before it is no longer effective. Results from testing across a thin-film fixed bed of the sorbent material illustrate that the regeneration process parameters can be varied to produce sorbents with different mercury capacities (Figure 6). The ability within the technology to vary these conditions can provide sorbents of varying capacity (and reactivity) and will allow the system to be economically optimized based on a number of process parameters. Note that, in Figure 6, the sorbents were regenerated with different reagent concentrations. Other acids covered under the technology application have been tested and have also shown similar results, thus further allowing for optimization and operational flexibility. These efforts have demonstrated initial technical viability of the technology, and planned testing will help optimize the technology and provide information to further the process design and perform economic evaluations.

Mercury Capture in a Wet Scrubber

The experimental conditions for the chlorination experiments are summarized in Table 1. Results showed that $\text{Hg}^0(\text{g}) + \text{Cl}_2$ chlorination is not hindered by SO_2 or H_2O independently. However, when combined, the effect of SO_2 and H_2O is significant. The oxidation ratio was reduced from 40% with SO_2 or H_2O alone to 5% when both were added. An additional experiment was carried out using HgCl_2 instead of $\text{Hg}^0(\text{g})$ to further explore the reaction mechanism. Results from this test showed the combined effect of the H_2O and SO_2 was to reduce HgCl_2 into $\text{Hg}^0(\text{g})$. The reduction of HgCl_2 reaches approximately 95% at a relatively high temperature, while neither H_2O nor SO_2 alone has a significant impact on HgCl_2 reduction.

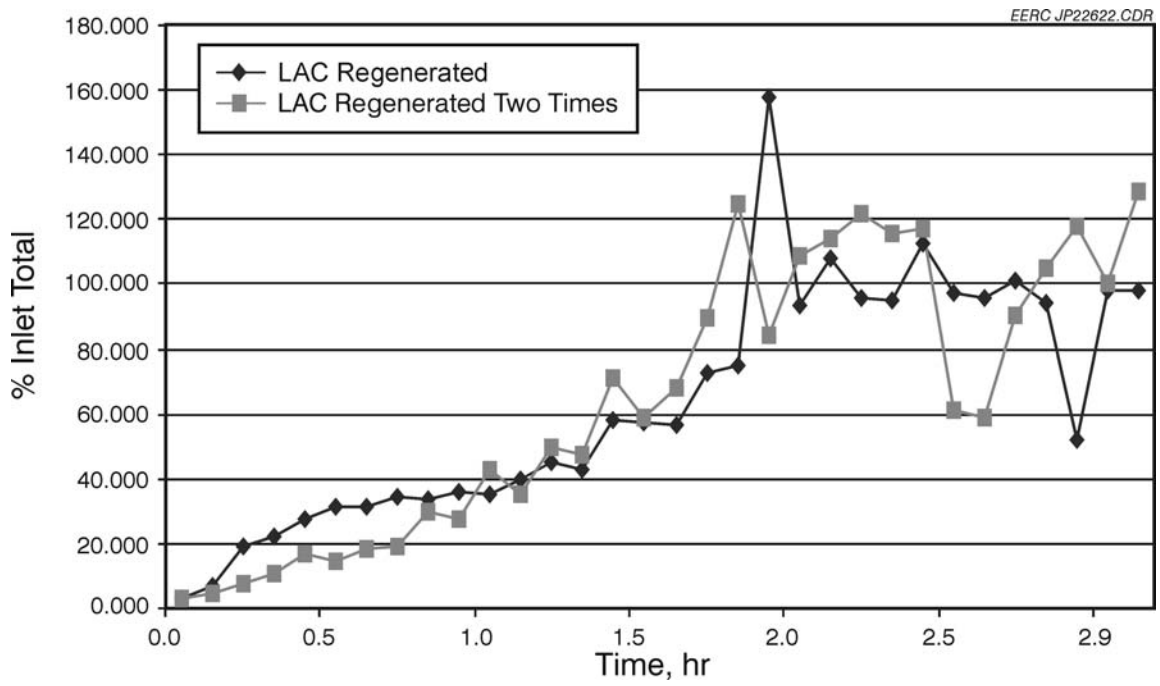


Figure 5. Typical Breakthrough for Regenerated Sorbent

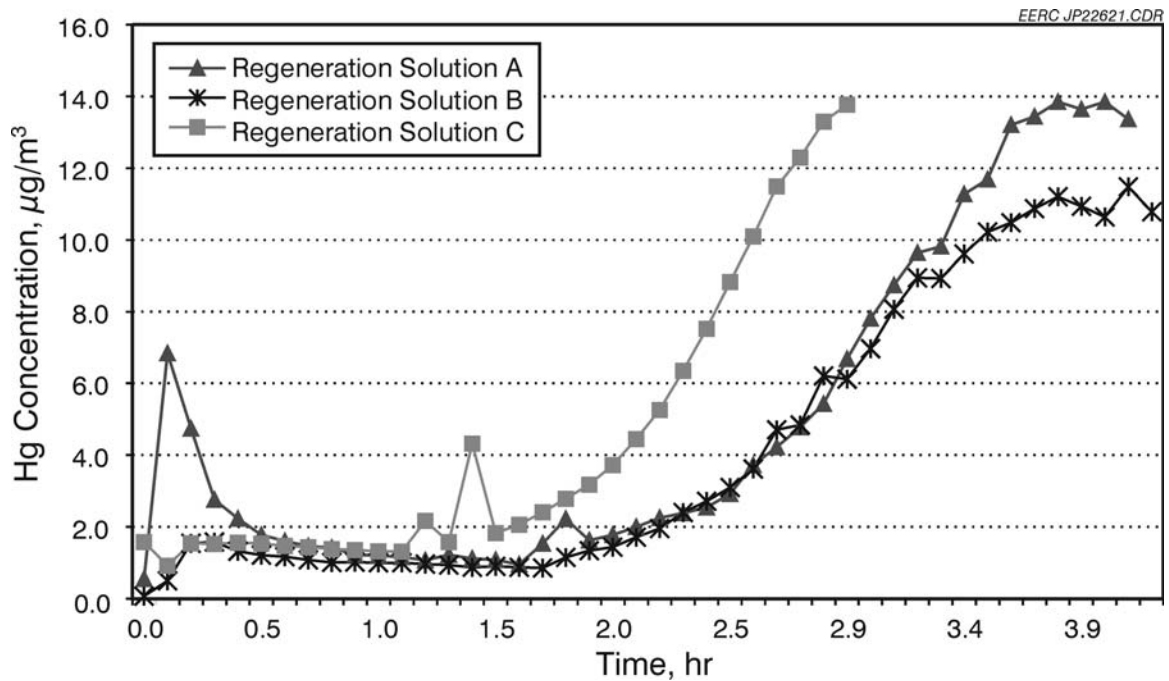


Figure 6. Effect of Acid Concentration on Sorbent Capacity

Table 1. Experimental Condition of the Reactions

Factors	Parameters
Flow Rate	14 Lpm
Reaction Section Length	65 cm
Reactor Internal Diameter	2.2 cm
Sampling Rate	14 Lpm
CO ₂	0%–12%
SO ₂	0–2000 ppmv
Cl ₂	0.1–100 ppmv
NO	0–600 ppmv
Hg ⁰ (g)	12 μg/m ³ (constant during test)
HgCl ₂ (g)	11 μg/m ³ (constant during test)
Reaction Temperature Preset	400°–800°C

NO_x is formed in all combustion processes. At high temperatures, NO is the dominant species, with a typical range from 100 to 1000 ppm. Dry NO has insignificant impact on mercury chlorination, whereas the addition of 8% H₂O results in a dramatic decrease in mercury chlorination levels, from 40% to approximately 5%. A similar observation was found in the HgCl₂ reaction system where HgCl₂ was reduced. CO₂ typically accounts for about 12% of the combustion flue gases. The impact of CO₂ is insignificant in either the oxidation or reduction of mercury species.

Experiments were designed to further clarify the interactive impacts of NO and SO₂ on mercury chlorination. The statistical results indicated that Hg⁰(g) oxidation averaged 85%, and there were no statistically significant interactions. The resulting data indicated that 20 ppm of Cl₂ was sufficient for nearly complete oxidation.

Status

Research is currently focused on understanding the role of SO₃ in the flue gas on poisoning carbon sorbents. Flue gas–mercury interactions on sorbents other than carbon are also being examined. Tests will be conducted with spent sorbents to isolate the oxidation gases in the simulated flue gas. Additional improvements in the proposed model for the oxidation and bonding mechanisms on the carbon sorbents are in progress as further details of the participation of carbon edge structures in the reactions are revealed.

Both the thin fixed-bed and the entrained-flow test systems will continue to be used to screen and compare sorbents.

Although a number of tests have been completed to evaluate sorbent regeneration techniques, more tests are still needed to help define the process limitations and to provide information directed at optimization of the technology. Several bench-scale tests are planned, and preparations are being made to do some pilot-scale testing. The goal is to gather enough information to demonstrate commercial potential.

Because of the difficulty in obtaining reasonable material balances across the CEPS, work directly utilizing the wet scrubber was discontinued. The remaining work focused on oxidation of Hg⁰ upstream of the wet FGD. Both heterogeneous and homogeneous reactions were investigated and a mercury reaction pathway hypothesized. Future work will focus on verifying the proposed reaction pathways.

Additional work will continue with the wet scrubber under funding from the North Dakota Experimental Program to Stimulate Competitive Research and the National Science Foundation. To minimize the adsorption of Hg^{2+} on the surface of the scrubber, a new unit is being fabricated which will be added to combustion facilities in the University of North Dakota Chemical Engineering Department. The spray tower and holding tank will be fabricated from glass. Methods and matrix design will be developed to evaluate the scrubber performance in capturing Hg^{2+} and impacts on mercury capture from flue gas/liquid ratio, SO_2 concentration, scrubbing solution pH value, mercury concentration, and gas velocity.

Quality Assurance/Quality Control

The EERC is committed to delivering consistent and high-quality research that meets client needs and expectations. In order to ensure that the goals of this project are realized, an organizationwide quality management system, authorized and supported by EERC managers, is in effect and governs all programs within the organization. This project is required to follow the Quality Manual, project-specific quality assurance (QA) procedures, and all revisions. The project manager is responsible for ensuring that project specific QA/quality control (QC) protocols are followed.

The EERC maintains a wide range of laboratories and equipment for solid, liquid, and gaseous characterization of the physical, chemical, mineralogical, biological, hydrological, and geological properties of natural and synthetic materials and processes. Laboratory procedures and instrument calibrations follow nationally recognized or approved standards and methods put forth by EPA, American Society for Testing and Materials, the National Institute of Standards and Technology, and other agencies. Each laboratory manager is responsible for ensuring that the applicable QA/QC procedures in this project are implemented.

The breakthrough curves generated with fixed-bed samples of AC have been used in the past to establish that the system is not mass transfer-limited and the effects of flue gas constituents on mercury capture and oxidation. Previous tests have established the repeatability of the results and demonstrated good mercury mass balances. The main quality objective of the bench-scale tests is to determine the mercury capacity of a given sorbent under different flue gas conditions.

The mercury concentrations at the inlet and the outlet of the fixed bed are measured with an atomic fluorescence mercury continuous emission monitor. The instrument is calibrated using standard injections of mercury vapor at known temperature and volume. The known inlet mercury concentration produced by the bench-scale system is measured before and after each test to ensure there have been no problems with the equipment during the test. The known inlet mercury concentration is based on the total flow rate of the flue gas constituents and the permeation rates of the Hg^0 and HgCl_2 sources. The flow rates are controlled by mass flow controllers which are periodically calibrated with a Gilibrator, which is a primary standard for flow measurement. The permeation rates of the mercury sources are periodically confirmed with either EPA Method 101A samples or Ontario Hydro samples.

Potential Users/Technology Transfer

The work is focused on technology development and potential applications in the utility industry. Information generated will assist EPA in determining appropriate regulations and assist utilities in developing mercury control strategies. Additionally, the successful identification of an inexpensive reactive sorbent for Hg control would be of potential benefit to other industries requiring a mercury control technology.

Assuming success, there should be many potential users, including coal-fired utilities across the world. Commercial offering of the technology will likely involve equipment suppliers (e.g., B&W, Alstom, and ADA-ES to name a few), and/or sorbent vendors.

References

1. Sjoström, S.; Harrington, P. Full-Scale Test of Mercury Control with Sorbent Injection and an ESP at Wisconsin Electric's Pleasant Prairie Power Plant. Presented at the Air & Waste Management Association 95th Annual Conference and Exhibition, Baltimore, MD, June 23–27, 2002.
2. Hassett, D.J.; Heebink, L.V.; Pflughoeft-Hassett, D.F. Potential for Mercury Release from Coal Combustion By-Products. In *Proceedings of the Air Quality III: Mercury, Trace Elements, and Particulate Matter Conference*; Arlington, VA, Sept 10–13, 2002.
3. Pflughoeft-Hassett, D.F.; Dockter, B.A.; Eylands, K.E.; Hassett, D.J.; Pavlish, J.H. Impact of Mercury Emission Control Technologies on Conventional Coal Combustion By-Product Management. Presented at the Air & Waste Management Association 89th Annual Meeting and Exhibition, Nashville, TN, June 23–28, 1996.
4. Miller, S.J.; Dunham, G.E.; Olson, E.S.; Brown D.T. *Fuel Processing Technology* **1999**, 65–66, 343–363.
5. Holmes, M.J.; Amrhein, G.T.; Bailey, R.T.; Downs, W.; Kudlac, G.A.; Madden, D.A. Advanced Emission Control Development Program, Phase III; Approved Final Report, McDermott Technology Inc., DOE Report No. DOE FETC Contract No. DE-FC22-94PC94251-22, July 1999.
6. Carey, T.R.; Skarupa, R.C.; Hargrove, O.W. Jr. Enhanced Control of Mercury and Other HAPS by Innovative Modification to Wet FGD Processes. Phase I Report for the U.S. Department of Energy, Contract DE-AC22-95PC95260, Aug 28, 1998.
7. Dunham, G.E.; Olson, E.S.; Miller, S.J. Impact of Flue Gas Constituents on Carbon Sorbents. In *Proceedings of the Air Quality II: Mercury, Trace Elements, and Particulate Matter Conference*; McLean, VA, Sept 19–21, 2000.
8. Olson, E.S.; Dunham, G.E.; Sharma, R.K.; Miller, S.J. Prepr. Pap.—Am. Chem. Soc., Div. of Fuel Chem. **2000**, 45 (4), 886–889.
9. Olson, E.S.; Laumb, J.D.; Benson, S.A.; Dunham, G.E.; Sharma, R.K.; Miller, S.J.; Pavlish, J.P. The Multiple Site Model for Flue Gas–Mercury Interactions on Activated Carbons: The Basic Site. *Prepr. Pap.—Am. Chem. Soc., Div. Fuel Chem.* **2003**, 48 (1), 30–31.
10. Radovic, L.R.; Bockrath, B. *Prepr. Pap.—Am. Chem. Soc., Div. Fuel Chem.* **2002**, 47 (2), 428.